PB-219 260

TRANSPORTATION CONTROL STRATEGY DEVELOPMENT FOR THE DENVER METROPOLITAN AREA

Fred Winkler

TRW Transportation and Environmental Operations

Prepared for:

Environmental Protection Agency

December 1972

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

APTD-1368

PB 219 260

TRANSPORTATION CONTROL STRATEGY DEVELOPMENT FOR THE DENVER METROPOLITAN AREA

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

137

BIBLIOGRAPHIC DATA SHEET	1. Report No. APTD-1368	2.	3. Recipient's Accession No. PB-219260
4. Title and Subtitle Transportation Control Strategy Development for the Denver Metropolitan Area.			5. Report Date December 1972 6.
7. Author(s)			8. Performing Organization Rept. No.
9. Performing Organization Name and Address TRW Transportation and Environmental Operations 7600 Colshire Drive McLean, Virginia 22101			10. Project/Task/Work Unit No. DU-72-8895 11. Contract/Grant No. 68-02-0041
12. Sponsoring Organization Name and Address Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, N.C. 27711			13. Type of Report & Period Covered Final Report 8/14/72 to 12/15/72 14.

15. Supplementary Notes Prepared to assist in the development of transportation control plans by those State Governments demonstrating that National Ambient Air Quality Standards cannot be attained by implementing emission standards for stationary sources only.

16. Abstracts

The document demonstrates the nature of the Air Quality problem attributed to motor vehicle operation, the magnitude of the problem and a strategy developed to neutralize these effects in order that National Ambient air quality standard may be attained and maintained.

17. Key Words and Document Analysis. 17a. Descriptors

Motor Vehicle emitted pollutants - air pollutants originating within a motor vehicle and released to the atmosphere.

National Ambient Air Quality Standards - Air Quality Standards promulgated by the Environmental Protection Agency and published as a Federal Regulation in the Federal Register.

17b. Identifiers/Open-Ended Terms

VMT - Vehicle Miles Traveled
Vehicle Mix - distribution of motor vehicle population by age group.
LDV - light duty vehicle - less than 6500 lbs.
HDV - heavy duty vehicle - greater than 6500 lbs.

17c. COSATI Field/Group Environmental Quality Control of Motor Vehicle Pollutants

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
For release to public	UNCLASSIFIED	all
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 3-72)

USCOMM-DC 14952-P72

APTD-1368

TRANSPORTATION CONTROL STRATEGY DEVELOPMENT FOR THE DENVER METROPOLITAN AREA

Prepared by

TRW Transportation and Environmental Operations
7600 Colshire Drive
McLean, Virginia 22101

Contract No. 68-02-0048

EPA Project Officer: Fred Winkler

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Water Programs
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

December 1972

LA

The APTD (Air Pollution Technical Data) series of reports is issued by the Office of Air Quality Planning and Standards, Office of Air and Water Programs, Environmental Protection Agency, to report technical data of interest to a limited number of readers. Copies of APTD reports are available free of charge to Federal employees, current contractors and grantees, and non-profit organizations - as supplies permit - from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or may be obtained, for a nominal cost, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

This report was furnished to the Environmental Protection Agency by TRW Transportation and Environmental Operations of McLean, Virgina, in fulfillment of Contract No. 68-02-0048. The contents of this report are reproduced herein as received from the TRW Transportation and Environmental Operations. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency.

Publication No. APTD-1368

TABLE OF CONTENTS

		Page
1.0	SUMMARY	1-1
	1.1 Conclusions and Recommendations	1-1
2.0	INTRODUCTION	2-1
	2.1 Program Purpose	2-1
	2.2 Problem Definition and Description	2-2
3.0	LIMITATIONS OF THE TRANSPORTATION CONTROL STRATEGY ANALYSIS	3-1
	3.1 Air Quality Monitoring	3-1
	3.2 Emission Factors	3-2
	3.3 Cold-Start Emissions	3-3
	3.4 Traffic Data and Projections	3-3
	3.5 Analytic Techniques Used	3-3
	3.6 Effects of Control Measures	3-4
4.0	CONTROL STRATEGY DEVELOPMENT	4-1
	4.1 Emission Estimates	4-1
	4.2 Control Measures Considered	4-2
	4.2.1 Exhaust Emission Controls	4-5
	4.2.2 VMT Reduction	4-8
	4.3 Proposed Control Strategy(s)	4-12
	4.3.1 Exhaust Emission Control Measures	4-17
	4.3.2 Recommended VMT Reduction Strategies	4-18
	4.4 Obstacles to Implementation	4-29
	4.4.1 New Car Standards	4-29
	4.4.2 Vehicle Inspection and Maintenance	4-30
	4.4.3 Retrofit of Pre-1968 Cars, High Altitude Modifications	4-30
	4.4.4 Vehicle Use Reduction	4-30
	4.4.5 Car Pooling	4-32
	4.4.6 Peripheral Parking, Exclusive Bus Lanes	4-32
	4.4.7 Improved Bus Transportation	4-32
	4.4.8 Long-Term Measures	4-33

TABLE OF CONTENTS
(continued)

	Page
5.0 CONTROL STRATEGY IMPLEMENTATION AND SURVEILLANCE	5-1
5.1 Air Quality Checkpoints	5-1
5.2 Transportation Checkpoints	5-4
5.3 Legislative Checkpoints	5-4
5.4 Administration	5-5
APPENDIX A - AIR QUALITY AND EMISSIONS DATA	A-1
APPENDIX B - TRANSPORTATION DATA BASE	B-1
APPENDIX C - TRANSPORTATION PLANNING ADVISORY COMMITTEE - RECOMMENDED PHASED STRATEGY ELEMENTS	C-1
APPENDIX D - DATA AND DOCUMENT LIST	D-1
APPENDIX E - AUTOMOBILE AIR POLLUTION QUESTIONNAIRE	E-1
APPENDIX F - VEHICLE EMISSION INSPECTION AND CONTROL PROGRAM.	F-1
APPENDIX G - TITLE 40, APPENDIX N	G-1

LIST OF TABLES

Table Number	Title	Page
4-1	Denver Emissions (Uncontrolled)	4-3
4-2	Percent Reductions Achievable (CO)	4-13
4-3	Percent Reductions Achievable (CO)	4-14
4-4	Percent Reductions Achievable (HC)	4-15
4-5	Percent Reductions Achievable (HC)	4-16
B-1	Vehicle Miles of Travel for the Central Area	B-5
B-2	Vehicle Miles of Travel for the Core Area	B-6
B-3	Vehicle Miles of Travel for the Five Zones in the Denver Metropolitan Area	B-7

LIST OF FIGURES

Figure Number	Title	Page
4-1	Analysis Areas	4-4
5-1	Surveillance Checkpoints - Phase I	5-2
5-2	Surveillance Checkpoints - Phase II	5-3
A-1	Sample Isopleth	A-2
A-2	CO (Maximum) Eight-Hour Monthly Average	A-6
A-3	Total Oxidants Peak-Hour Monthly Maximum	A-6
B-1	Denver Grid	B-2
C-1	Rough Draft of Phase I of Transportation Planning Advisory Committee Recommendations	C-1'
C-2	Rough Draft of Phase II	C-2
C-3	Rought Draft of Phase I, Section III	C-3
E-1	Automobile Air Pollution Questionnaire	E-14

1.0 SUMMARY

Subsequent to the provisions of the Clean Air Act of 1970, the State of Colorado must submit a definitive transportation control plan to the Environmental Protection Agency by February 15, 1973. As support for this plan, TRW and its subsidiary DeLeuw, Cather and Company have compiled an analysis of the impact of transportation sources on existing and projected air quality and recommendations for elements of control plan sufficient to meet the Federal requirements for carbon monoxide and oxidant air quality.

1.1 CONCLUSIONS AND RECOMMENDATIONS

From the qualitative and quantitative analyses of existing data and recommendations for the control of transportation related carbon monoxide and hydrocarbon emissions the following conclusions can be stated:

1. The Federal standard for eight-hour carbon monoxide will require a 64% reduction in carbon monoxide emissions by 1977. The peak-hour oxidant data indicate a 32% reduction is required in the 6-9 AM hydrocarbon emissions.
2. Federal new car standards will not be sufficient to meet the required reduction by 1977.
3. No one control measure will be sufficient to meet the required carbon monoxide reduction.
4. A region-wide plan is required to
   a. Prevent the deterioration of air quality in areas not currently exceeding the standards and
   b. To reduce the region-wide contribution to the accumulation of pollutants in maximum concentration areas.
5. The region-wide plan would consist of
   a. Those control measures which will effectively reduce the region-wide contribution to the formation of critical concentrations of which some combination of the following is considered most feasible and effective:
      - Inspection/Maintenance
      - Hi-Altitude Retrofit
      - Pre-1968 Retrofit

b. Those control measures which will reduce the emissions in critical concentration areas resulting from high density vehicle miles of travel (VMT) at low average vehicle speeds.

c. Those long-term measures which in addition to those mentioned above will insure that existing air quality in the region is not degraded. These measures should include:

- land use planning with attention to transportation related environmental factors
- tax reforms to reverse the existing encouragement for additional cars and/or VMT tax.
- planned development of a regional public transportation system in conjunction with land-use planning.

On the basis of these conclusions the following recommendations are made:

1. Establish immediately a testing facility to adequately measure the uncontrolled and controlled emissions at high altitudes. This facility should also test the proposed retrofit devices especially the high altitude modifications. Use this facility to test the findings of the Northrop Study (see Appendix F).

2. Expand the regional monitoring network for carbon monoxide and oxidants.

3. On the basis of test results and the findings of the Northrop Study, select an Inspection and Maintenance and retrofit program most effective at high altitudes and phase implementation of this program to achieve total impact by June 1976 at the latest.

4. On the basis of test results and the findings of the Northrop Study, determine the retrofit packages most effective for the Denver area (with special attention to high altitude retrofits) and phase implementation of this program to achieve full impact by June 1976 at the latest.

5. Implementation of those VMT reduction measures directed at the central area (until extended monitoring indicates extension to other areas) and consisting primarily of:

   - Regional bus network improvements
   - Peripheral parking
   - Car pooling

   and those restraints necessary to insure the effectiveness of these measures, namely

   - curb parking removal

   Although further restraints such as taxation may be required to support a large modal shift, they require careful consideration of socio-economic impact and demand elasticity modeling before implementation.

6. Utilize the modal split, trip distribution, and economic analyses being carried out by the Council of Governments and the Regional transportation District and long range planning program to postulate alternative restraints and transportation impacts on the total transportation network. This effort will focus on long-term measures to assure the maintenance of ambient standards.

7. Update the emissions and air quality data base on the basis of monitoring and test results at least semi-annually during the period January 1973 to July 1976.

8. Re-define if necessary the air quality problem on the basis of the updated inventory and any modeling performed and

9. Re-evaluate and re-define the elements of the control strategy where necessary, at least semi-annually between January, 1973 and July, 1976.

2.0 INTRODUCTION

2.1 PROGRAM PURPOSE

The State of Colorado must submit definitive transportation control plans to the Environmental Protection Agency (EPA) no later than February 15, 1973, for those areas of the State, namely Denver, where emissions from transportation sources have resulted in concentrations of pollutants in excess of the national ambient air quality standards. To assist the State in its preparation of this transportation plan, EPA has awarded a contract to TRW Inc., and its subsidiary De Leuw, Cather and Company for developing strategies for the Denver metropolitan area that will achieve carbon monoxide and oxidant air quality standards required to be met by the year 1977. In the performance of this program the following tasks were performed:

1. Implementation Plan Review to verify and assess the severity of the carbon monoxide and oxidant pollutant problem.
2. Identification of Transportation Controls. These strategies considered the impact of the required 1975 systems controls as well as the assessment of the feasibility of achieving control as established by the Six Cities Study.
3. Estimate of Air Quality Impact. Estimate of the likely impact anticipated from each of the control techniques using established rollback or modeling methods. The method of estimation and rationale are given in Appendix A.
4. Documentation of Implementation Obstacles. The contractor met with local air pollution and transportation agencies responsible for implementing the recommended controls for the purpose of identifying obstacles that can be expected in the implementation process.
5. Formulation of Surveillance Review Process. The formulation of a timetable of key checkpoints to be used by EPA in monitoring implementation progress in achieving transportation control. The timetable includes the period January, 1973 through December, 1976.

2.2 PROBLEM DEFINITION AND DESCRIPTION

The physical and climatic characteristics of the Denver metropolitan area impose a finite limitation on the allowable emission density for the area if ambient air quality standards are to be met. Mobile source emissions are responsible for 97% of the total carbon monoxide emissions and 70% of the hydrocarbon emissions in the metropolitan Denver area. Superimposed on this physical environment is a high vehicle population growth rate (5.2%/year) and the highest per capita automobile ownership in the nation. The combined impact of these physical and social characteristics is to partially offset the expected benefits from the incursion of controlled automobiles into the vehicle population.

The 1971 CAMP station air quality data show a 64% reduction in carbon monoxide emissions required to meet the Federal eight-hour standard. The hydrocarbon emissions must be reduced by 32% in order to bring the peak hour oxidant values within Federal requirements. Air quality and emissions data are given in Appendix A to this report.

The emissions estimates given in Section 4.1 and the transportation data in Appendix B indicate the source of the pollutants is strongest in the center of the city. However, the outer parts of the metropolitan area contribute substantially, therefore any program designed to reduce extreme pollution levels should not be limited to the reduction of miximum emissions area, but should include some plan for area-wide reductions. It should also be noted that although the CAMP station data support the conclusion that areas of high vehicle miles traveled (VMT) and therefore high emissions are areas of high pollutant concentration, the meteorological and physical factors documented by Riehl and Herkhof[1] strongly suggest that other high concentration areas may well exist which are not currently monitored.

---

[1] Riehl, Herbert and Herkhof, Dirk, "Weather Factors in Denver Air Pollution," August 1970.

3.0 LIMITATIONS OF THE TRANSPORTATION CONTROL STRATEGY ANALYSIS

The basic requirement which any acceptable air pollution control strategy must meet is that emission levels following implementation of the strategy are consistent with the attainment and maintenance of National Ambient Air Quality Standards. Satisfaction of this requirement depends upon a detailed knowledge of current air quality levels and a quantification of the pollutant emissions in the region. Additionally, an implementable transportation control strategy must consider the economic factors associated with its adoption and also the social and political changes necessary to accommodate each specific control measure. The air quality benefits of any action must be thus balanced against the social and economic dislocations caused by its implementation. Long-term regional transportation goals and policies must be balanced against the need to achieve specific degrees of emission reduction by 1977. Limitations in the data available and in the analytic method used became obvious during the course of this study, and care must be taken in the interpretation and evaluation of the control strategy recommendations contained in this report. Several specific areas in which the present study needs to be confirmed and validated by future study are listed below.

3.1 AIR QUALITY MONITORING

Two basic areas of concern appear in connection with air quality data available for this project. First and most important, ambient monitoring at only one point completely fails to give an adequate appreciation of the regional character of the air pollution problem. It is impossible to determine whether the monitor is being adversely affected by local sources and thus giving unrealistically high readings in terms of the regional problem or conversely, whether there are areas of maximum ambient pollution that are being completely unmonitored. The only solution to this problem lies in increasing the number and geographical spread of ambient monitors. Data from the extended monitoring network should be used to constantly evaluate and update the control strategy presented in this document. The second problem concerning the use of air quality monitoring data lies in the statistical manipulations and projections used to determine the required

level of reduction for the attainment of standards. Basing an extensive control program on measurements obtained in one or two hours per year may lead to the imposition of unduly strict control measures. The trend of ambient measurements during the period before the target year of 1977 must be carefully watched and used to adjust control measures according to observed ambient conditions. Further, specific high measurements obviously due to adverse meteorological conditions may be considered as episode control situations and may not require the imposition of long-term transportation control strategies for their solution.

3.2 EMISSION FACTORS

The mobile source emission estimates utilized in this study are based upon the best currently available emission factor estimates. These emission estimates are in the process of updating and revision with both in-use and new vehicle testing programs, conducted by the Environmental Protection Agency. The applicability of the standard testing driving cycle to the driving patterns in each metropolitan area is questionable. Further, there are many trip types making up the total vehicle miles traveled in each area; and it has not been possible on the basis of currently available data to distinguish in an air pollution emissions sense between the different driving modes used. It is highly recommended that new emission factors be utilized as they become available to recompute and redefine the severity of the mobile source generated emissions in the region. Finally, the emission factors used in the study relate speed to emissions only on the basis of the integrated driving cycle. This has prevented the accurate assessment of changes in emissions due to improvement in traffic flow characteristics in core, center city areas.

3.3 COLD-START EMISSIONS

Preliminary data have shown that the emissions generated during the first few minutes of vehicle operations represent a large and increasing portion of the total emissions during any individual vehicle trip. The implications of this fact are that to truly reduce mobile source emissions it may be necessary to address the reduction in total vehicle trips rather than merely reducing the number of vehicles miles traveled. Unfortunately, the data relating to this phenomena were not sufficiently developed to be used in the analysis presented in this study. A potential control strategy to reduce the high level of cold start emissions might be the direct control of emissions from parking structures which act as stationary sources. Again, it has not been possible to quantitatively describe the effect of this type measure on the regional air pollution problem in this report.

3.4 TRAFFIC DATA AND PROJECTIONS

Traffic data and traffic projections have not historically been collected with a view to the estimation of motor vehicle air pollution emissions. This fact has necessitated the reworking of traffic data including vehicle flows, speeds and modal mixes into the format necessary for emission calculations. Certain assumptions and potential inaccuracies have been introduced by this process. Further the use of trends and projections in vehicle growth have been prepared by various agencies and often little unanimity has been found concerning appropriate growth rates. These data in certain cases require that a close watch be maintained both on traffic changes and ambient air quality during the period between now and full strategy implementation so that any deviations from the expected vehicle emission rates can be determined and appropriate adjustments made in the control strategy. It should be noted that stationary source emission projections also suffer from inaccuracies in the projection of industrial growth and in the application of as yet untested control technologies to control of these stationary sources.

3.5 ANALYTIC TECHNIQUES USED

The key analytic calculation performed in this study is the relation between emission levels and ambient air quality. Diffusion modeling

techniques were used to a limited degree in the "Six Cities Transportation Project" to predict air quality for the Denver area, however, the analysis indicated that the technique was inadequate to describe the physical and meteorological characteristics of the Denver Basin. Due to time restraints, it was not possible to develop more sophisticated mathematical modeling techniques to describe these characteristics. Control strategy reductions were therefore based on proportional roll-back techniques relating emissions and air quality on a proportional basis. The use of modeling is highly recommended since in addition to consideration of local meteorological and topographical effects, it can indicate the georgraphical distribution of the pollution problem. Such modeling and simulation exercises, using models currently under development or the models to be developed through the grant request submitted to EPA by the Colorado Air Pollution Control Commission, should be carried out during the period between January 1973, and 1977. The results of these efforts should be used to modify, if necessary, the control strategy recommended in this document.

3.6 EFFECTS OF CONTROL MEASURES

It was generally not possible to expressly quantify the emission reduction effect of many of the control measures considered in this document. For example, the effect of the inspection and maintenance program depends strongly upon the exact test procedure used, maintenance recommendations, the quality and availability of trained mechanics and a host of other factors which were impossible to define exactly during this study. Similarly, mass transit improvements can be expected to reduce vehicle miles traveled within the region. However, the extent of this reduction is unknown and specific data concerning the economic elasticity of the various travel demands, the modal split of trips within the region, and many other factors need to be carefully evaluated before a quantitative estimate can be prepared.

It is strongly recommended that programs be instituted to provide additional data and to apply more sophisticated analytic techniques in the areas listed above. Work must begin upon the implementation of the required regional control measures; however, final implementation and enforcement should be dependent upon data collected during calendar years 1973, 1974, and even 1975. Full consideration must be given to the political,

jurisdictional and social impact of all control actions. The control strategy presented in this document must be considered as an initial attempt to quantify the relationship between transportation processes and the regional air pollution problem. The further study indicated should be used to modify this baseline effort. The air pollution implications of the transportation process are very complex and a modification of this process can potentially effect significant changes in the social and economic character of the metropolitan region.

4.0 CONTROL STRATEGY DEVELOPMENT

Transportation control measures must be defined which will reduce mobile source emissions to a level which will achieve compliance with the Federal air quality standards. The technical approach is to select candidate control measures and quantify where possible the emissions reductions expected. Control strategy development includes the following tasks:

- Development of a transportation data base - The details of this development are given in Appendix B.
- Development of an air quality and emissions data base - Air quality data are summarized in Appendix A. Baseline emissions estimates are given in Section 4.1.
- Definition of Control Measures - Transportation control measures fall into two categories; exhaust emission reductions and reduction of vehicle miles traveled (VMT). These control measures may be both long and short term and region-wide or area specific in extent. Exhaust emission control measures are discussed in Section 4.2.1 and VMT reductions are discussed in Section 4.2.2 to this report.
- Development of strategy application data - These data are described in Sections 4.3 and the Appendices.
- Analysis of the impact of strategies on air quality. The procedures and rationale for emissions estimates are given in Appendix A. The percent reductions achievable for each strategy are summarized in Section 4.3.
- Development of control strategy - A control strategy consists of one or several compatible control measures. The control strategy elements considered most feasible for the Denver metropolitan area are described in Section 4.3.

4.1 EMISSION ESTIMATES

An emission estimate is the product of two factors; vehicle miles traveled (VMT) and an emission factor or rate. The emission factors used in this study are based on measured and projected emission rates for each vehicle

class considering age of vehicle, effectiveness of emission controls, average speed, and vehicle age distribution. The impact of Federal new car standards is considered in both the present and projected vehicles. The emission factor development followed the procedure developed by Kircher and Armstrong[1] of the EPA. The details of the procedure are given in Appendix A. Vehicle miles traveled and speed were determined as shown in Appendix B.

Table 4.1 shows the emission estimates for CO, hydrocarbons, and NO_x respectively for current and projected conditions considering only currently planned transportation systems and assuming the 1975 new car standards will be met. Figures 4.1 shows the analysis areas in Table 4.1. These analysis areas are defined in detail in Appendix B.

A 64% reduction in carbon monoxide emissions would not be met until at least 1980. If stationary source emissions are allowed to increase at the 2% per year rate suggested in the implementation plan, they may become a significant factor.

The 32% reduction in hydrocarbon emissions will be achieved by 1977 throughout the Denver city-county area.

4.2 CONTROL MEASURES CONSIDERED

The control measures described in the "Report and Recommendations from the Transportation Planning Advisory Committee to the Colorado Air Pollution Control Commission" adequately cover the spectrum of possible types of control measures. These measures are grouped into two categories, emission reductions through emissions control devices and their maintenance and VMT reductions. Acknowledging the efforts and merit of this committee's work TRW has elected to expand and quantify where possible the impact of these types of control measures. These measures are discussed below.

---

(1) D.S. Kircher and D.P. Armstrong, "An Interim Report on Motor Vehicle Emission Estimation," Environmental Protection Agency, October 1972.

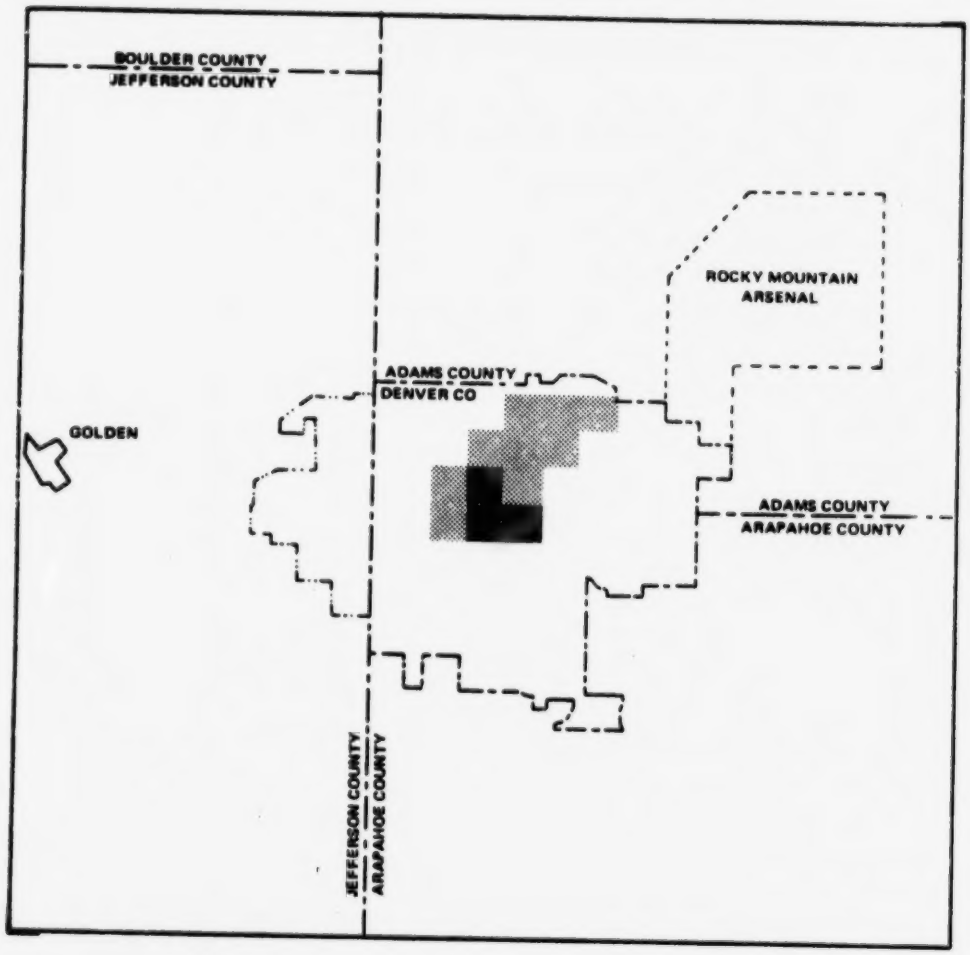
DENVER EMISSIONS (Uncontrolled)*

T/Day

		LDV			HDV			DIESEL			STATIONARY
		Core	CA	Denver	Core	CA	Denver	Core	CA	Denver	Denver
CO	1971	72.7	148.9	483.2	6.4	13.0	42.3	0.0	0.1	0.3	13.0
	1977	37.6	90.5	304.9	5.3	11.2	37.6	0.0	0.1	0.4	14.7
	1978	31.7	68.5	234.1	5.0	10.7	36.4	0.0	0.1	0.4	15.0
	1980	21.0	47.0	162.1	4.6	10.2	34.8	0.0	0.1	0.4	15.6
HC	1971	7.7	18.2	62.3	1.0	2.2	7.5	0.0	0.0	0.1	35.9
	1977	3.7	8.9	31.2	0.7	1.7	5.9	0.0	0.0	0.1	40.4
	1978	3.1	7.6	26.8	0.7	1.6	5.6	0.0	0.0	0.1	41.2
	1980	2.1	5.3	18.8	0.6	1.5	5.1	0.0	0.0	0.1	42.9
NO_x	1971	1.5	4.3	15.6	0.2	0.5	1.7	0.0	0.1	0.6	54.2
	1977	1.0	3.1	11.7	0.2	0.5	2.0	0.1	0.2	0.7	61.1
	1978	1.0	3.0	11.6	0.2	0.5	2.0	0.1	0.2	0.7	62.3
	1980	0.9	2.7	10.5	0.2	0.5	2.1	0.1	0.2	0.7	64.8

CA - central area
LDV - light duty vehicles
HDV - heavy duty gasoline vehicles
*Federal new car standards are assumed to be met by 1975.

TABLE 4.1



- Central Area

- Core

Fig. 4.1 Analysis Areas

4.2.1 Exhaust Emission Controls

Four major types of exhaust emission control programs have been considered as follows:

- Federal emissions control requirements for new cars
- Inspection/Maintenance (I/M)
- Retrofit of Light Duty Vehicles (LDV)
- Gaseous fuels conversion

The major advantage of this group of controls is that their impact is region-wide in extent rather than area specific. The necessity for a region-wide plan has been considered in Section 3.2 above. However it should be reiterated that a plan based solely on a "chronic" approach, that is the reduction of emissions in the maximum concentration and emissions areas only, fails to recognize the prevelent meteorological and physical characteristics of the Denver area which cause all emission areas to contribute to the formation of critical concentration areas. It also fails to recognize that critical concentration areas may exist which are not currently monitored or may exist in the near future due to inadequately planned growth which does not consider transportation requirements or resultant air quality deterioration.

Each of the four types of exhaust emission control programs are discussed briefly below. They are each discussed in detail in the EPA document "Control Strategies for In-Use Vehicles". The specific elements of these programs currently planned or being considered as most effective for the Denver region are described in more detail in Section 4.3.and Appendix F and G

- Federal emissions control requirements for new cars.
  The Federal 1975 standards for new cars are assumed to be met.

- Inspection/Maintenance (I/M)
  The many varieties of Inspection and Maintenance programs and their benefits are described in detail in the EPA document "Control Strategies for In-Use Vehicles," and the IPA/TRW report "Evaluating Transportation Controls To Reduce Motor Vehicle Emissions in Major Metropolitan Areas." The revised Title 40 of

the Federal Register in Appendix N defines the requirements for an acceptable program and the expected reductions achievable. An "Inspection/Maintenance" program is defined as a means to reduce emissions from in-use vehicles through identifying vehicles that need emissions control related maintenance and requiring that maintenance be performed. The reason that such a program can achieve additional reductions is that current in-use emission control devices deteriorate or their effectiveness deteriorates due to other automotive parameters such as a poorly tuned engine. Therefore, the purpose of an Inspection/Maintenance program is to maintain exhaust emissions from in-use vehicles as close to the standards of the new vehicle as possible (whether controlled or uncontrolled) and thereby gain the maximum benefit from emissions control technology. An Inspection/Maintenance program is also a requirement (see Title 40) of any retrofit program.

A particular advantage of such a program for the Denver metropolitan area is that it requires (see Title 40) "provisions for the establishment of inspection failure criteria consistent with claimed reductions." Some limited tests by EPA in the region and the State APCD indicate new cars do not meet their claimed reductions due to the effects of high altitude. However, there is no provision exempting high altitude areas from the Federal standards for air quality and no provision for exemption of new vehicles from emission standards at high altitudes, therefore an inspection/maintenance program can show a deficiency which is the responsibility of the manufacturer as well as the owner.

The requirements for an acceptable I/M program as found in the revised Title 40 of the Federal Register are attached to this report as Appendix G. Appendix F to this report is the final report summary volume from the Northrop/Olson Laboratories evaluation of "Vehicle Emission Inspection and Control Program" conducted for the Colorado Department of Health to determine the technical and economic feasibility and public acceptability of a vehicle emission inspection and control program. The conclusions

and recommendations from the Northrop study are summarized in Section 4.3 and it is suggested that with some documentation by testing, this study could form the basis for an Inspection/Maintenance program for Denver.

Retrofit of Light Duty Vehicles (LDV)

Again the details of the major types of retrofit deveices for in-use vehicles are described in "Control Strategies for In-Use Vehicles" and two retrofit packages for pre-controlled vehicles are studied and described in the Northrop report (see Appendices F and G).

The majority of retrofit devices are designed for installation in pre-controlled or pre-1968 light duty vehicles though some can be effective on other vehicles. There are two prime considerations for retrofit devices; which pollutant do they most effectively reduce and what segment of the automotive population is effected. Vehicle age-distribution projections for Denver indicate that by 1977 only 8% of the LDV population will be pre-1968 or uncontrolled. Although the retrofit devices are very effective in reducing emissions from these vehicles the added reduction in total emissions for all light duty vehicles is very small by 1977 (about 1 to 6% of total LDV emissions). There are, however, two advantages to this control measure; its impact is region-wide, and it is directed at the worst polluters.

Two retrofit packages for pre-1968 LDV are considered most feasible and effective for the reduction of carbon monoxide emissions by the Northrop Study. These are summarized in Section 4.3 and Appendix F. A retrofit package considered highly effective for hydrocarbon emissions was considered in addition in Section 4.3 and is described in more detail in Appendix G and the EPA guide.

A high-altitude modification package designed by Pontiac Motor Division in Denver appears to be highly effective in reducing emissions for 1972 GM vehicles. Preliminary results indicate this

package or a similar design is applicable to all domestic LDVs for possibly 1968 to 1974 model years. Because of the possibility of a large segment of the vehicle population being affected, this package could be highly effective in reducing total emissions. Further testing is certainly required and highly recommended.

Gaseous Fuel Conversion

Recommendation for the use of gaseous fuel conversion is limited to metropolitan areas where large, centrally located fleets represent significant portions of the total vehicle miles of travel (VMT). It is further restricted by the limited supply of such fuels in many areas. Since such significantly large central fleets do not exist in Denver and any gaseous conversion would detract from the supply of available low polluting gases, this form of exhaust emission control measure is not recommended.

4.2.2 VMT Reduction

The alternative to exhaust emission control measures are those measures which reduce the vehicle miles of travel (VMT). These measures are most effective in areas of very high VMT concentration. The area of current maximum VMT concentration is in the immediate vicinity of the CAMP station and indicates the necessity for severe emission reductions. This is not to imply that other high concentration areas do not exist, however it is apparent that the most feasible exhaust emission control programs may be insufficient to meet the required reductions in this area and that some form of VMT reduction program may be required.

The following short-term and long-term approaches to VMT and emission reductions are a summary of the measures considered by the Transportation Planning Advisory Committee. Those measures considered most effective and most feasible are discussed in detail in Section 4.3. Although only the short-term measures are considered for detailed analyses, the regional transportation program and other long-term measures are noted as having the potential for effects beyond 1980. The advantage to long-term regional planning is the prevention of the formation of critical concentration areas resulting from high density VMT at low average speeds.

In October 1972, the Transportation Planning Advisory Committee to the Colorado Air Pollution Control Commission issued a report setting forth alternative proposals for exhaust emission controls and vehicle use reduction aimed toward meeting the National Ambient Air Quality Standards in the Denver Metropolitan Region. The Committee also recommended transportation control strategies which they believed could be achieved by July 1977. Strategies for actual control of exhaust emissions are discussed elsewhere in this report and this section will deal specifically with recommendations of the Committee pertaining to vehicle use reduction.

One of the principal recommendations of the Committee from a standpoint of short-term public transportation improvements dealt with the establishment of a regional bus network which would serve the people of the entire Denver Metropolitan Air Quality Control Region. Other recommendations for public transportation improvements included elimination of curb parking and establishment of exclusive bus lanes and express bus routes. Peripheral parking in bus stations was considered which would provide major loading points from which express buses could operate into the Central Area.

It was clear to the Committee that short-term public transportation improvements followed by a long-term plan were absolutely essential if the Federal primary and secondary standards are to be achieved.

The second category of vehicle restraints considered by the Committee recognized that public transportation improvements alone would not attract riders from private automobiles and reduce carbon monoxide levels sufficiently unless vehicle restraint methods were employed. Restraints considered included some form of wheel taxation which would discourage ownership of second and third family automobiles, and a parking tax which could perhaps be applied to the peak hours or in specific critical areas.

In addition, the Committee discussed possibilities of bypass techniques and traffic control improvements which might have an impact on total traffic flow and emission rates in critical areas. It was not believed that these recommendations would have a major impact since it is generally recognized that such techniques are already widely being used throughout the Denver region, and on an average traffic flow within the region is now and will in the future be much more efficient than eastern cities of comparable character and size.

The Committee recognized that increasing package delivery service on a voluntary basis by the business community could be a significant step toward reduction in the daily number of shopper trips to the Central Area. Road use regulations, including techniques such as metering of freeways, special peak-hour restrictions, freeway exit penalties, and car-free zones within critical areas were also considered.

Income tax reform which would allow the public transportation commuter deduction on his personal State Income Tax was suggested as an incentive for the use of public transit. Finally, the concept of work schedule changes was considered. It was recognized that this concept would not necessarily reduce the total number of vehicle miles of travel during a 24-hour period and might discourage car pooling techniques.

Strategies of a more long-range nature included consideration of the environmental restraints in planning the future relationships between transportation and land use. In addition, the Committee wholeheartedly endorses the legislation passed by the State of Colorado in 1969 creating the Regional Transportation District. Charged to the RTD is the creation of a public transportation system for the seven-county region which will significantly change the modal split between automobile and public transit travel.

From the various alternatives considered, the Committee recommended strategies consisting of short-range public transportation improvements including establishment of a regional bus network, express routes, and exclusive bus lanes. A program of peripheral parking supported by express routes into the Central Area was recommended. The Committee further recommended short-range strategy of vehicle restraints which included removal of key street parking, parking taxes in critical areas during critical times, and a wheel taxation aimed toward the discouragement of second and third vehicles in a family.

The Committee further recommended possible road use regulations and peak-hour license plate restrictions which would have required operators of motor vehicles during the peak hours to have special license plates which would be at a premium for controlling the number of vehicles that would be moving during critical pollution periods. The Committee further recommended voluntary establishment of commercial delivery services for businesses in the Central Area so as to discourage the necessity of travel to the Central Area.

In addition, the Committee believes that some form of income tax reform which would provide a deduction on the State Personal Income Tax for the cost of public transportation to work by commuters to be a logical form of incentive for use of public transportation.

4.3 PROPOSED CONTROL STRATEGY(S)

The analyses of the control measures considered most feasible for implementation by 1977 show that no one control measure will be sufficient to meet the required reduction for carbon monoxide. The reductions achievable by several combinations of control measures are shown in Tables 4.2-4.5. The strategies considered are as follows:

- STRATEGY 1 - I&M, LIA/VSAD - Inspection/Maintenance, Lean Idle Air Fuel Ratio/vacuum spark advance disconnect

  This strategy is totally exhaust control oriented. It consists of either key mode or idle inspection and maintenance with twice yearly inspection, LIA/VSAD retrofit for pre-1968 light duty vehicles.

- STRATEGY 2 - I&M, LIA/ITM - Inspection/Maintenance, Lean Idle Air Fuel Ratio/Ignition timing Modification

  Inspection/Maintenance as above with LIA/ITM retrofit for pre-1968 vehicles. The primary difference between strategy 1 & 2 is the greater impact on CO of the Ignition Timing Modifications.

- STRATEGY 3 - VMT Reductions -

  This strategy does not include any exhaust controls with the exception of Federal new car controls. The maximum reduction is achieved in the core area. The suggested measures are 1) regional bus network improvements, 2) peripheral parking, 3) car pooling, and those restraints necessary to ensure the effectiveness of these measures, namely curb parking removal. These are described in detail in Section 4.3.2.

- STRATEGY 4 - Combined STRATEGY 1 and STRATEGY 3 -

  VMT reductions are combined with the exhaust control measures in STRATEGY 1 above.

- STRATEGY 5 - Combined STRATEGY 2 and STRATEGY 3 -

  VMT reductions are combined with exhaust control measures of STRATEGY 2 above.

PERCENT REDUCTIONS ACHIEVABLE*

CO (LDV only)

LDV (not incl sta. source)	Denver		CA		Core	
	Emissions T/day	Reduct %	Emissions T/day	Reduct %	Emissions T/day	Reduct %
1971	483.2	-	148.9	-	72.9	-
Fed. New Car	304.9	36.9	90.5	39.2	37.6	48.3
STRAT I I&M, LIA/VSAD	227.2	53.0	67.0	55.0	31.4	56.8
STRAT II I&M, LIA/ITM	210.8	56.4	62.2	58.2	29.1	60.0
STRAT III VMT Reduct.	295.4	38.9	84.6	43.2	34.5	52.5
STRAT IV I + III	220.2	54.4	62.7	57.9	28.8	60.4
STRAT V II + III	204.3	57.7	58.1	61.0	26.7	63.3

CA - Central Area

*Reductions from 1971 all include 1975 standards

Table 4.2

PERCENT REDUCTIONS ACHIEVABLE*
CO (TOTAL EMISSIONS)

Total (% Reduction Required 64)	Denver		CA		Core	
	Emissions	Reduct	Emissions	Reduct	Emissions	Reduct
	T/day	%	T/day	%	T/day	%
1971	538.8	–	162.0	–	79.1	–
Fed. New Car	357.6	33.6	101.8	37.2	42.9	45.8
STRAT I	279.9	48.1	78.3	51.7	36.7	53.6
STRAT II	263.5	51.1	73.5	54.6	34.4	56.5
STRAT III	348.1	35.4	95.9	40.8	39.8	49.7
STRAT IV	272.9	49.4	74.0	54.3	34.1	56.9
STRAT V	257.0	52.3	69.4	57.2	32.0	59.5

CA - Central Area

*Reductions from 1971 all include 1975 standards

Table 4.3

PERCENT REDUCTIONS ACHIEVABLE*
HC (LDV only)

LDV (not incl sta. sources	Denver		CA		Core	
	Emissions T/day	Reduct %	Emissions T/day	Reduct %	Emissions T/day	Reduct %
1971	62.3	-	18.2	-	7.7	-
Fed New Car	31.2	49.9	8.9	51.1	3.7	51.9
STRAT I	26.0	58.3	7.3	59.9	3.0	61.0
STRAT II	26.1	58.1	7.4	59.3	3.1	59.7
STRAT III	30.2	51.5	8.3	54.4	3.4	55.8
STRAT IV	25.2	59.6	6.9	62.1	2.8	63.6
STRAT V	25.3	59.4	6.9	62.1	2.8	63.6

CA - Central Area

*Reductions from 1971 all include 1975 standards

Table 4.4

PERCENT REDUCTIONS ACHIEVABLE*

HC (TOTAL EMISSIONS)

Total (% Reduction Required 32)	Denver		CA		Core	
	Emissions	Reduct	Emissions	Reduct	Emissions	Reduct
	T/day	%	T/day	%	T/day	%
1971	105.8	–	20.4	–	8.7	–
Fed. New Car	77.6	26.7	10.6	48.0	4.4	49.4
STRAT I	72.4	31.6	9.0	55.9	3.7	57.5
STRAT II	72.5	31.5	9.1	55.4	3.8	56.3
STRAT III	76.6	27.6	10.0	51.0	4.1	52.9
STRAT IV	71.6	32.3	8.6	57.8	3.5	59.8
STRAT V	71.7	32.2	8.6	57.8	3.5	59.8

CA - Central Area

*Reductions from 1971 all include 1975 standards

Table 4.5

The above strategies are considered conservative in their estimates of emission reduction possible; however, no strategy will precisely achieve the 64% reduction required even in the core area where VMT reduction impact is greatest. No consideration has been given to any high-altitude retrofit package due to lack of data. The reduction achievable by implementation of this exhaust control measure will definitely be sufficient in combination with STRATEGY 4 or STRATEGY 5 above to meet the required reduction for the core and central areas.

Based on the figures in Table 4.3 it is recommended that STRATEGY 5 (with the additional high-altitude retrofit package) be adopted as the transportation control plan for Denver. Although this strategy results in essentially the same hydrocarbon reduction as STRATEGY 4, it was selected because of its higher carbon monoxide reduction. STRATEGY 5 is made up of exhaust emission controls described in detail in Appendices F and G, and VMT reduction measures discussed in Section 4.3.2.

4.3.1 Exhaust Emission Control Measures

- **Inspection/Maintenance and Retrofit**

  The Northrop/Olson Laboratory study summary is attached as Appendix G to this report and is considered the most detailed analysis of these control measures specific to the Denver area available. It is recommended that the conclusions of this study be tested in a hi-altitude testing facility as soon as possible. The most likely impact on CO emissions reductions for light duty vehicles for several combinations of exhaust controls is shown in Table 4.2 Table 4.3 shows the impact of these strategies on total CO emissions. Tables 4.4 and 4.5 show the impact of these strategies on light duty vehicle (LDV) hydrocarbon emissions and total hydrocarbon emissions respectively.

4.3.2 Recommended VMT Reduction Strategies

The impact of many of the control strategies described in Section 4.2.2 cannot be assessed in quantitative terms by themselves. In many instances they constitute segments of more comprehensive programs which can, based on experience in other communities and upon extensive mathematical modeling of economic and transportation patterns, serve as a basis for quantifying reductions in vehicle travel and resulting economic consequences.

For example, the impact of the removal of curb parking for the purpose of establishing exclusive bus lanes cannot in itself be quantified. Most certainly, however, this among other innovations tends to improve the overall quality of bus service that can be measured in total in terms of experience in other cities. From the combination of strategies considered by the Committee and by the consultants, three major strategies on which the consultant believes that a quantitative assessment of reduction in vehicle travel can be placed are derived.

The first of these is establishment of a regional bus network and provision of a greatly improved transit service. The second strategy hinges around provision of peripheral parking served by adequate access to the central Area, and encouragement of the use of this peripheral parking service. The third strategy hinges around encouragement of car pooling for travel to the Central Area and the restraints necessary to bring about increased car pooling.

Regional Bus Network and Improved Service

In 1969 the State of Colorado created legislation establishing the Regional Transportation District. This District was given responsibility for development of long-range plans for transportation--both highway and transit--to serve the seven-county Denver region. But such planning takes time to develop and to implement. The City and County of Denver, therefore, in 1969 retained the services of W. C. Gilman & Co., Inc., to develop a short-range public transportation plan for Denver and to determine the feasibility of public acquisition of the Denver Tramway Corporation. The

Gilman study postulated three alternative levels of transit service for the City of Denver. The first of these assumed that the present level of service would be maintained under public ownership. Capital funds sufficient to maintain a modern bus fleet and provide substantial improvements to bus stop amenities were included. A modest marketing program was also included in the plan.

Under the second alternative, it was assumed that the vehicle miles and vehicle hours of transit service would be expanded by approximately ten percent in the first year of public ownership and four percent each year thereafter. Specific service increases would be developed by the Schedule Department in cooperation with the Director of Marketing to ensure that maximum system efficiency is obtained.

The third alternative system assumed a greatly improved service in addition to increases in off-peak services in a new route. This alternative provided for significant increases in suburban services, thereby making the bus system more truly regional in scope. This third alternative is closely aligned to the concept of a regional system recommended by a Transportation Planning Advisory Committee to the Colorado Air Pollution Control Commission. In their report, Gilman pointed out the effect of a combination of transit improvements coupled with proper marketing and customer relations was difficult to predict. On the basis of experience in San Diego, however, where public acquisition of the transit service was followed by a broad program of improvements, the consultants (W. C. Gilman) estimated that a target ridership increase of 25 percent over the first two years of public ownership was a realizable goal. They further estimated that annual increases of two percent per year would be postulated for succeeding years. To accomplish this, W. C. Gilman recommended that service be increased by 15 percent in the first year, 10 percent the following year, and four percent thereafter.

Transit patronage in Denver had declined from approximately 40 million passengers per year in 1960 to less than 13.5 million per year in 1971.

On April 18, 1971, the City and County of Denver acquired the transit system. Significant extensions of service into suburban areas, new routes, and other service improvements were made and over the first 12 months of public ownership, ridership of the Denver Metro Transit Service has increased to levels approximately 20 percent higher than ridership during the previous 12 months. This represented an increase from approximately 13.4 million riders in 1971 to approximately 16.2 million in 1972. Thus, it becomes apparent that the W. C. Gilman & Co., Inc.'s, forecasts of the potential increases in transit patronage which might result with a significantly improved service will be more than realiz able. Because these forecasts are based on far more extensive study than could be carried out as a part of this program, they are accepted for purposes of this analysis.

On the basis of the W. C. Gilman & Co. forecasts and the accuracy of these forecasts to date, it is estimated that bus patronage on an average day in 1977 will be approximately 50 percent greater than in 1971, or 20 million passengers per year or a minimum of approximately 24,000 passengers per day in 1971. Since the 1971 base year estimates of the vehicle miles of automobile travel and the screen line analyses from which forecasts of annual rates of increase in vehicle travel for the central area were developed did not assume significant improvements in bus service, the increased transit patronage resulting from the improved service is assumed to have a direct effect on the reduction in vehicle miles of travel by automobile.

Of the anticipated increase of 24,000 passengers per day between the 1971 base year and the 1977 projection year, it is estimated that approxi- mately 90 percent will have destinations in the Core. Thus, the 24,000 bus passengers per day increase will result in a reduction of approximately 21,500 auto passenger trips to and from the CBD core. It is assumed that the entire 24,000 trips would result in reduction of automobile travel to the 12 square mile central area. The resulting reductions in vehicle miles of travel within various analyses districts would be as follows:

- Within the Core three square miles -- 21,500 passengers at 1.1 persons per vehicle and 1.2 vehicle miles of travel would result in a reduction of approximately 23,500 vehicle miles of travel, or a 3.8 percent reduction in total vehicle miles of travel on an average weekday in 1977.
- Within the Central Area 12 square miles -- 24,00 passengers diverted to buses at 1.1 persons per vehicle times 2.5 vehicle miles of travel results in a reduction of approximately 55,000 vehicle miles, or a 3.0 percent reduction in total travel on an average weekday in 1977.
- Within the City of Denver, including the central area and the CBD core, the 24,000 passengers diverted to buses at an average of 1.1 persons per passenger vehicle and an average trip length of 4.5 miles equals a reduction of approximately 100,000 vehicle miles of travel, or 1.4 percent for the entire City of Denver on an average weekday in 1977.

The above increase in transit patronage is brought about entirely by improvements in service. The increase is not contingent on restraints, such as increased parking fees in the Central Business District or other restrictions, in order to become a reality. The total cost to the community of the improved bus service is discussed in the W. D. Gilman & Company report of October 1970 and has been elaborated on by later studies by the Regional Transportation District.

Economic justification of the improved service has been based on the need to provide a more balanced regional transportation service and it will be difficult to assess the proportion of the total subsidy being paid by the City of Denver and the suburban communities that should be assignable to resulting reduction in emissions and improvement in air quality which would result.

Peripheral Parking

In their report entitled, "Parking in Downtown Denver" submitted to the Department of Public Works of the City and County of Denver on April 1, 1971, Alan M. Voorhees & Associates, Inc., estimated that the total demand for travel to the Denver central business district core would increase from approximately 270,000 person trips per day in 1970 to 320,000 person trips per day in 1980. Assuming the transit patronage between these years

could conceivably double, Voorhees estimates that the resulting impact on auto driver trips to the central business district core will be an increase from 138,000 one way in 1970 to 180,000 in 1980. This represents a 30 percent increase over ten years, or approximately an 18 percent increase between the base year of 1971 and the forecast year of 1977 considered in this study. This would result in approximately 165,000 vehicle trips in 1977.

The Voorhees study recommended four new parking garages which would provide downtown Denver with approximately 5,650 additional off-street parking spaces. These were intended to meet the 1980 demand only in part for additional parking required to meet the increased vehicle travel.

The estimated 138,000 vehicle trips to and from the central business district core on an average day in 1970 represented approximately 30 percent of the total vehicle miles of travel within the three square mile core and 20 percent of the total vehicle miles of travel within the 12 square mile central area. Total travel through the core area will not increase at the same rate as travel to and from the area. Based on the 1980 Voorhees projections of total vehicle trips to and from the core, it is estimated that in 1977 these trips will represent 33 percent of the total vehicle miles of travel within the three square mile central business district core and 22 percent of the total vehicle miles of travel within the 12 square mile central area.

As a rebuttal to the Voorhees plan, the Plan Metro Denver Committee in March 1972 presented an Interim Transportation Plan for the City and County of Denver and other selected portion of the Denver Metropolitan area. This plan recommended establishment of an extensive system of peripheral parking facilities could have impact on reduction in future travel to the critical areas.

The City and County of Denver now encourages use of parking facilities at Mile High Stadium -- bus service into the downtown area now operates from the stadium at approximately five-minute headways during the peak period and at greater headways during the off-peak. The buses enter the downtown area from the west across 23rd Street. Usage of the stadium parking areas has been disappointing, however. Until recently the parking rates were high and buses between the stadium and the central area competed with crowded city streets during rush hours.

Studies of a personal rapid transit (PRT) system now under way which would provide some type of facility connecting the Mile High Stadium with the Medical Center, and proposed parking facilities along Colorado Boulevard could provide a spine along which other peripheral parking facilities and bus interchange points could be located. Parkers and transit patrons would then be able to gain access directly to the central business district core without competing with surface traffic.

The proposed PRT system is still in the study stage and it is not likely that it will be implemented in time for consideration as a part of the control strategy aimed toward attainment of the 1977 air quality standards.

The most likely means of connecting peripheral parking facilities with the central area over the next six years will be buses operating on surface streets. If a system of peripheral parking spaces could be located three mile or more than the central business district core and adequate bus service to the core provided, the resulting impact of each 5,000 spaces on total travel demands would be as follows:

> Within the Core -- a reduction of 5,000 parking spaces times a 1.2 times turnover in space usage times both an inbound and outbound trip at 1.2 vehicle miles per trip would result in a reduction of approximately 14,000 vehicle miles of travel, or 2 percent in the total vehicle miles of travel taking place within the three square mile core on an average day.

- Within the Central Area -- 5,000 fringe parking spaces at 1.2 time turnover and one trip in each direction times 2.5 vehicle miles of travel for each direction would result in a reduction of approximately 30,000 vehicle miles of travel, or 1.5 percent reduction in total vehicle miles of travel in the 12 square mile central area on an average day in 1977.
- Within the entire City of Denver -- the impact of each 5,000 peripheral parking spaces on total travel demand would be a reduction of 30,000 vehicle miles of travel or 0.43 percent of total vehicle miles of travel demand within the City of Denver on an average day in 1977.

Establishment of an attractive system of peripheral parking facilities will not in itself attract vehicles to these facilities or result in reductions in the vehicle miles of travel within the central area or core. Attractive service between the peripheral facilities and the core area must be provided and restraints to discourage continued parking within the core must also be established. These restraints could include such things as a tax on core area parking, the income from which could be applied toward subsidy of the peripheral parking facilities. In addition, licensing restrictions within the core area might also be established. Abolishment of the 3,000 curb parking spaces remaining in the core could serve as incentive to utilization of peripheral facilities without creating an economic hardship on operators of existing private facilities.

The exact extent to which utilization of peripheral parking facilities could be stimulated by restrictions imposed within the core area cannot be determined without more sophisticated economic analyses than are possible under this study. The modal split, trip distribution, and economic analyses being carried out by the Joint Regional Planning Program of which the Council of Governments, the Regional Transportation District, and Colorado Department of Transportation in connection with their current development of a long-range transportation plan for the Denver region should serve as an excellent means of postulating the alternative restraints and the transit feeder service necessary to encourage use of peripheral facilities.

Car Pooling

The average vehicle occupancy rate in 1970 for all trips into downtown Denver was 1.3 persons per vehicle according to the Voorhees parking study. The average vehicle occupancy rate of work trips was 1.1 persons per vehicle. Both occupancy rates are lower than nationwide averages and can be attributed in part to the high vehicle ownership per capita and the ease of automobile travel in the Denver region.

The Transportation Planning Advisory Committee has suggested encouragement of car pooling as a realistic means of reducing travel to and from the central area.

If, for example, one out of every ten of the approximately 165,000 vehicle trips to or from the central business district parking study area in 1977 (according to the Voorhees growth rates) were to carry one additional passenger, the resulting impact on 1977 travel to the central area would be a transfer of 16,500 persons representing 12,500 automobile trips assuming an occupancy rate of 1.3 persons per vehicle. The impact of the reduction of this number of auto trips would be as follows:

- Within the Core -- 12,500 automobile trips either inbound or outbound at 1.2 miles of travel, a reduction of 15,000 vehicle miles of travel, or 2.5 percent of the 1977 average daily vehicle miles of travel within the core.
- Within the Central Area -- these same vehicles generating trip lengths of 2.5 miles of travel each represent a reduction of 37,500 vehicle miles or 2.0 percent of the total vehicle miles of travel into the central area on an average weekday in 1977.
- Within the City -- these same vehicles would have an average trip length of approximately four miles in each direction and would represent a reduction of 50,000 vehicle miles of travel, or 0.7 percent of the 1977 average daily total for the city.

It would not be realistic to assume that extensive car pooling could be encouraged in the Denver metropolitan area entirely on a voluntary basis. Certain control measures will be necessary for stimulation. The Committee suggests the possibility of special licensing which would permit only emergency or essential vehicles and other vehicles with, say, an average occupancy of two or three persons to park within restricted areas of the Central Business District.

A wheel tax or other form of taxation aimed toward discouragement of second and third family automobile making such vehicles unavailable for travel to work should also stimulate car pooling.

In conclusion, there appear to be three major strategies for which reductions in travel by automobile can be quantified.

Establishment of the regional bus system which has taken place following public acquisition last year and continued expansion in routes, headways, and other services will have a directly measurable effect on usage of the private automobile which will require no restrictions in order to be realized.

Establishment of the regional bus sytem and the improvements discussed above coupled with restrictions such as:

- Parking taxes in the central area
- Wheel taxes discouraging second and third family automobiles

will have a further impact on private automobile travel that can only be measured in realistic terms through the types of modal split and sensitivity analyses presently being undertaken by the Joint Regional Planning Program under the sponsorship of the Denver Regional Council of Governments.

Establishment of a series of peripheral parking facilities at distances one and one-half miles or greater from the central business area could have an impact on reduction of travel within the core and the central area if coupled with the following restrictions:

- Taxation on parking within the central area
- Removal of remaining curb parking within the central area

The above strategy must be coupled with adequate transit services from peripheral facilities and a favorable rate differential between the core and peripheral parking facilities. The tax on core area parking could be used to subsidize the peripheral facilities. The exact extent to which use of peripheral parking facilities could be effective can only be determined by actual demonstration and detailed trip distribution and sensitivity analyses which are beyond the scope of this study.

Car pooling could have a significant effect on travel to the central area if stimulated by:

- Special licenses restricted in the core area
- Parking taxes in the core area
- Removal of remaining curb parking and wheel tax discouraging second and third family vehicles

Again, while numbers can be quantified for this strategy, they can only be substantiated through more sophisticated modal split and sensitivity analyses.

Other long-range strategies including development of an extensive transit system in the Denver region, development of a PRT system in the central business district and coordinated planning of land use and transportation systems will also have long-range impacts which w.ll extend beyond 1977 and will not contribute significantly to automobile travel reductions in that year.

Other more severe strategies restricting use of the private automobile could be recommended. These could be costly and subject to attack if considered on the basis of the travel forecasts and air monitoring data made available for use in this study. It is the consultant's opinion that costly and potentially controversial strategies which would have a major impact on the economic and social character of the Denver region should not be recommended and would not be defensible until a more comprehensive network of continuous monitoring stations can be established to determine the impact of the more palatable strategies.

The percent reduction achievable for each area considered for VMT reduction above is shown by Strategy 3 in Tables 4.2 - 4.5. In combination with exhaust controls these measures approach the required CO reduction shown by Strategy 4 and Strategy 5.

4.4 OBSTACLES TO IMPLEMENTATION

Each of the major categories of air pollution control measures has a varying potential for effective implementation in the Denver study area. The mail panel survey [1] of Denver area residents indicated a greater awareness of a nationwide air pollution problem than a Colorado air pollution problem. Acceptability responses of various control measures were conditioned by the financial cost to them, the degree to which they might be limited in the use of their automobiles, and the inconvenience of the control measures. Long-term measures, such as public transportation improvements, generally are acceptable and desirable even though reducing air pollution may not be the primary reason for implementing this measure.

On other specific actions which would be required as segments of other measures, the panel survey was inconclusive. For example, a tax on all day parking, and any restriction on non-essential auto travel had approximately as many respondents for as against these measures.

The primary control measures reducing air pollution--that of fitting control devices to cars and mandatory inspections to assure the continued effectiveness--seem to be the most acceptable both to Denver citizens as represented by the Mail Panel and to public officials contacted.

4.4.1 New Car Standards

The Federal new car pollution standards seem to have been accepted and anticipated with little concern for increased costs for new cars so equipped.

1-See Appendix E for complete discussion of the mail panel survey.

4.4.2 Vehicle Inspection and Maintenance

With Colorado's experience in state agency inspections, two factors must be designed into the inspection process and specifically included in expanded enabling legislation. The inspection charges must be reasonable--about 85% of the mail panel survey favored a fee of less than $5 annually--and it must be convenient. Over 52% of the survey respondents favored inspections by the franchised service stations and garages. About 36% favored state operated inspection stations. During various discussions in Denver, some opposition was encountered to having an inspection program imposed on a statewide basis to solve a Denver metropolitan problem.

4.4.3 Retrofit of Pre-1968 Cars, High Altitude Modifications

The ease of adopting legislation to require the installation of retrofit devices on cars built before 1968 and adding high altitude modifications to new cars will be directly related to the cost of installing their devices. While 73% of the panel respondents favored this action if it cost under $50, only 30% felt that it would be justified at a cost of $200 per car.

Costs for retrofitting pre-1968 motor vehicles in the $200 range could be equal to or in excess of the actual market value of the car. To the extent that this level of cost might eliminate the 2nd car in a family, it would be beneficial to reducing air pollution from light duty vehicles. Although the ownership of older cars by level of income is not known, this requirement could impose a serious financial burden on lower income families.

With a $10 to $15 installation cost, the high altitude modification equipment presently available for installation on late model Pontiacs does not have either the financial or social implications of the pre-1968 retrofit devices. It is assumed that similar equipment will become available for all late model light duty vehicles.

4.4.4 Vehicle Use Reduction

The predominant opposition (75% or better) to vehicle restraints suggested by the mail survey indicates restraints are not measures readily acceptable by the public. Suggested measures included such constraints as a very high ($500) registration fee, gasoline rationing, or tolls on exit ramps of freeways.

Inherent to constraining the use of the automobile is the mandatory provision of making available some alternative mode of transportation. Therefore, the air pollution control strategies group envisioned improved bus transportation with the motor vehicle use restrictions. The plan suggests two traffic restricting measures in the study area of Denver: (1) creating effective CBD peripheral parking; and (2) encouraging car pooling.

More severe restrictions on the use of motor vehicles could be recommended. However, on the basis of travel forecasts made available for this study and limited air monitoring data, these measures could become controversial. They will have a major impact on the economic and social character of the Denver region. It is recommended that several actions be undertaken to increase the ability to quantify the effectiveness of these control measures before actually implementing them.

A network of air monitoring stations must be established throughout the region to (1) obtain comprehensive air data for evaluation; (2) determine the actual impact of the more palatable inspection and retrofit controls; and (3) to support the need for the more severe traffic restrictive controls. Traffic forecasts measuring effects of alternative approaches to emission factors, and refinement of modal use and sensitivity analysis also should be undertaken.

Based on these continuing studies, a greater refinement in the air pollution analysis can be undertaken, pollution criteria reevaluated, and more accurate quantification of solutions undertaken to support a greater reliance on the appropriateness of the required control measures.

Pending adequate basic data for imposing control measures requiring massive outlays of public funds, economically impacting major areas of the city, or requiring the resident to substantially modify his travel habits, the less severe measures which can be initiated include the following.

4.4.5 Car Pooling

Encouraging car pooling can result in some reduction of air pollution without major social or economic impacts. Respondents to the survey indicated that 5-6% now participate in car pools, another 50% indicated an interest in them, but only about 10% indicated that, if necessary, it would be easy to get into one.

4.4.6 Peripheral Parking, Exclusive Bus Lanes

The two most acceptable motor vehicle restraints (60-65%) indicated by survey respondents where creating exlusive bus lanes, and prohibiting traffic or parking in the CBD. Any prohibition of traffic or parking in the CBD, however, will require an effective program of peripheral parking and transit within the CBD. Increased effectiveness of the present "park-and-ride" program at Mile High Stadium, and the proposed "PRT"--Personnel Rapid Transit--demonstration will be necessary. Both of these control measures assumes an improved bus transportation.

4.4.7 Improved Bus Transportation

The improvement of the municipal owned bus service is currently underway. The air pollution control measures have assumed that these improvements will continue as planned and include such such service improvements as: express bus service, exclusive bus lanes, peripheral parking, "PRT" personnel rapid transit, regional bus network, and greater improved transit service.

Refinement of presently used mechanisms for furnishing bus service outside the City of Denver, or additional legislation will be necessary.

Although major economic investments will be required, they have already been justified as a cost of a balanced transportation system.

4.4.8 Long-Term Measures

Planning programs have already been established and work is presently underway to achieve the coordination of land use planning and transportation-related environmental factors, and for a mass transportation network throughout the region.

These acceptable long-term approaches to solving urban problems are generally accepted by both the citizens surveyed and the public officials contacted. Although not initially justified for the reduction of air pollution, they furnish one of the more acceptable long-term measures to accomplish this goal.

5.0 CONTROL STRATEGY IMPLEMENTATION AND SURVEILLANCE

A definitive time and procedure schedule for an implementation plan will require resolution of the questions pertaining to problem definition and control measure effectiveness. Since many of these areas require frequent evaluation to include the findings of on-going studies and monitoring, it is recommended that the implementation plan be phased and flexible in order to incorporate these refinements.

Such a phased plan is envisioned by the Colorado Air Pollustion Control Commission Transportation Planning Advisory Committee; a rough draft of this phased plan is shown in Appendix C. Th e plan consists of two major elements; Regional Transportation (RTD) and Vehicle Use Reduction. A third major element - a program for motor vehicle emission reductions through inspection/maintenance and retrofit devices is now in a draft form and is presented in Appendix C.

Surveillance checkpoints for this plan could be grouped into four categories as follows:

Air Quality Checkpoints
Transportation Checkpoints
Legislative Checkpoints
Administrative Checkpoints

Possible checkpoints for the two phases of this plan and for each of the three elements of the control strategy are discussed in the following sections. and are summarized in Figures 5.1 and 5.2

5.1 AIR QUALITY CHECKPOINTS

Data concerning the completion of each Air Quality Checkpoint should be obtained from the Air Pollution Control Division of the Colorado Department of Health.

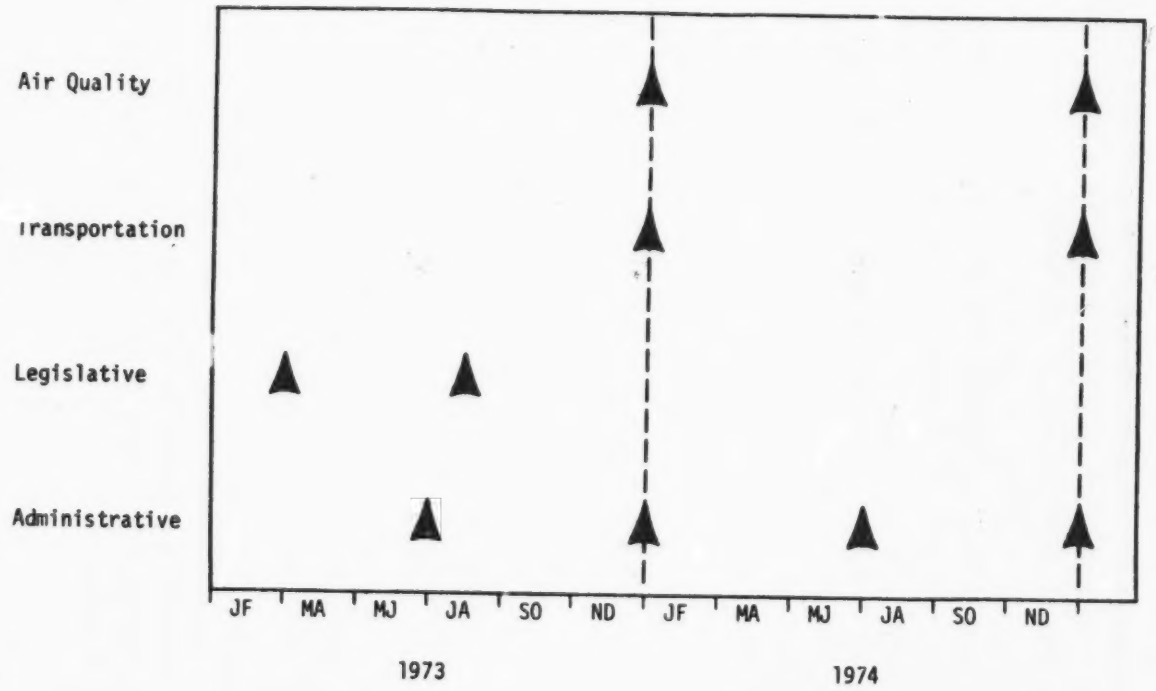


Figure 5-1. SURVEILLANCE CHECKPOINTS
Phase I

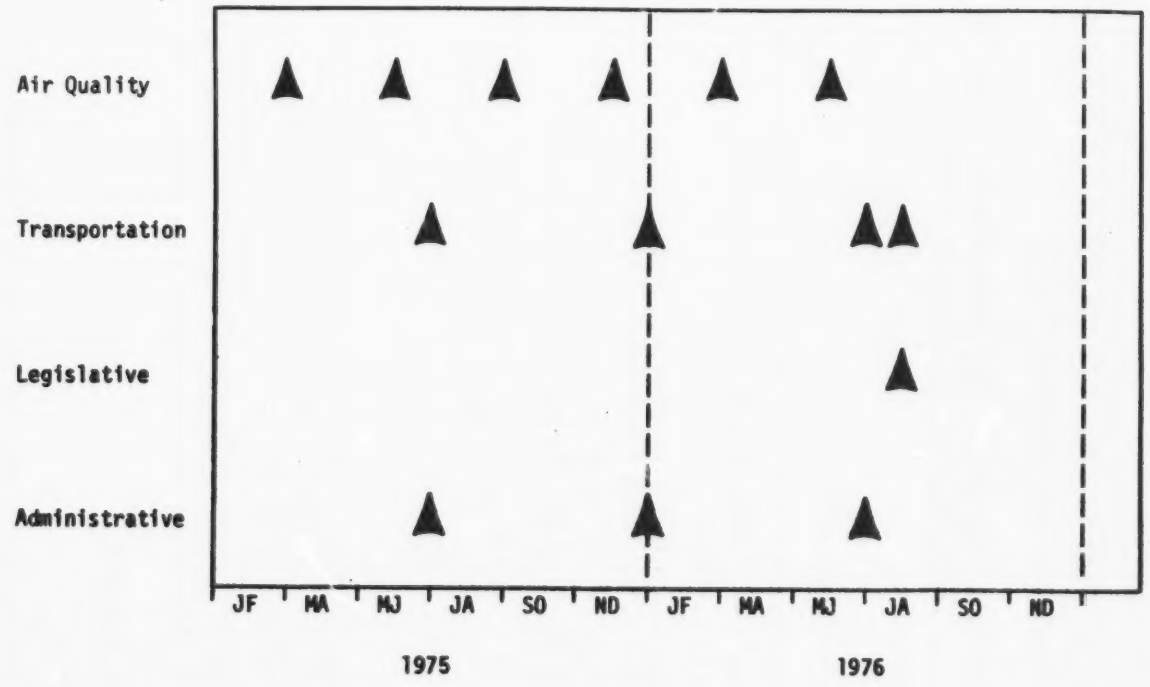


Figure 5-2. SURVEILLANCE CHECKPOINTS
Phase II

Phase 1 - The completion of Phase 1 scheduled for the end of 1974 would require the following:

1. Monitoring network complete by December 1973
2. One full year of data from this network available by December 1974
3. Evaluation of regional extent and severity of the air quality problem on the basis of one full year of data from the completed monitoring network.

Phase 2 - During the remainder of the interim program, air quality data should be reported seasonally as a minimum to note any seasonal trends.

5.2 TRANSPORTATION CHECKPOINTS

Phase 1 - The following checkpoints related to the transportation data base and control strategy elements initiated during 1973 and 1974 should be considered:

1. Annual evaluation of VMT growth and origin-destination data available from Department of Highways
2. Annual evaluation of projected regional transportation growth to include modal split analysis and demand elasticity modeling; data available from DRCOG.
3. Completion by December 1974 of high altitude testing and evaluation of inspection/maintenance and retrofit alternatives; data available from Colorado Air Pollution Control Commission

Phase 2

1. Completion of strategy element implementation by July 1976; data available from the Colorado Air Pollution Control Commission and the Air Pollution Control Division of the Colorado Department of Health.
2. Semi-annual evaluation of transportation related emissions by the Testing Laboratory of the Air Pollution Control Division of the Department of Health.

5.3 LEGISLATIVE CHECKPOINTS

Phase 1

1. February 1973 - enabling legislation drafted by the Colorado Air Pollution Control Commission.

2. July 1973 - enabling legislation adopted by the State Legislature

Phase 2

1. July 1976 - enabling legislation implemented by the Air Pollution Control Division of the Colorado Department of Health

5.4 ADMINISTRATION

The degree of implementation of the control measures should be summarized and evaluated every six months to ensure compliance with overall control strategy. This could best be done by requiring the implementing agencies to make status reports to the state and regional control agencies.

APPENDIX A
AIR QUALITY AND EMISSIONS DATA

THE PROPORTIONAL AIR QUALITY MODEL

The emission reduction required for carbon monoxide was determined by use of the roll-back technique.

Calculations are as follows:

$$R = \frac{A - C}{A - B} \times 100$$

where: A = Cmax = 24.6 ppm (8 hr. ave)
B = background concentration = 0
C = national standard = 9 ppm

$$R = \frac{24.6 - 9.0}{24.6 - 0} = .64$$

The emission reduction required for hydrocarbons was determined by utilizing the relationship given in Appendix J of the Federal Register (vol. 36, no. 228, Nov. 25, 1971, p. 22413).

The maximum peak hour oxidant reading for 1971 was considered to be 0.12 ppm. This requires a 32% hydrocarbon reduction.

The Gifford-Hanna diffusion model was applied to Denver in the "Six Cities Study" (1). The analysis showed the model is inadequate to describe the maximum concentration conditions caused by a combination of stagnation accumulation and channeling effects. However, the diffusion pattern for max concentration conditions could be useful in land use planning. A sample isopleth of the eight-hour maximum concentration dispersion pattern predicted by the model is shown in figure A-1. Numerical concentration values are not adequate for comparison with ambient data and should not be used for planning purposes.

(1) TRW, Prediction of the Effects of Transportation Controls on Air Quality in Major Metropolitan Areas, Nov. 1972

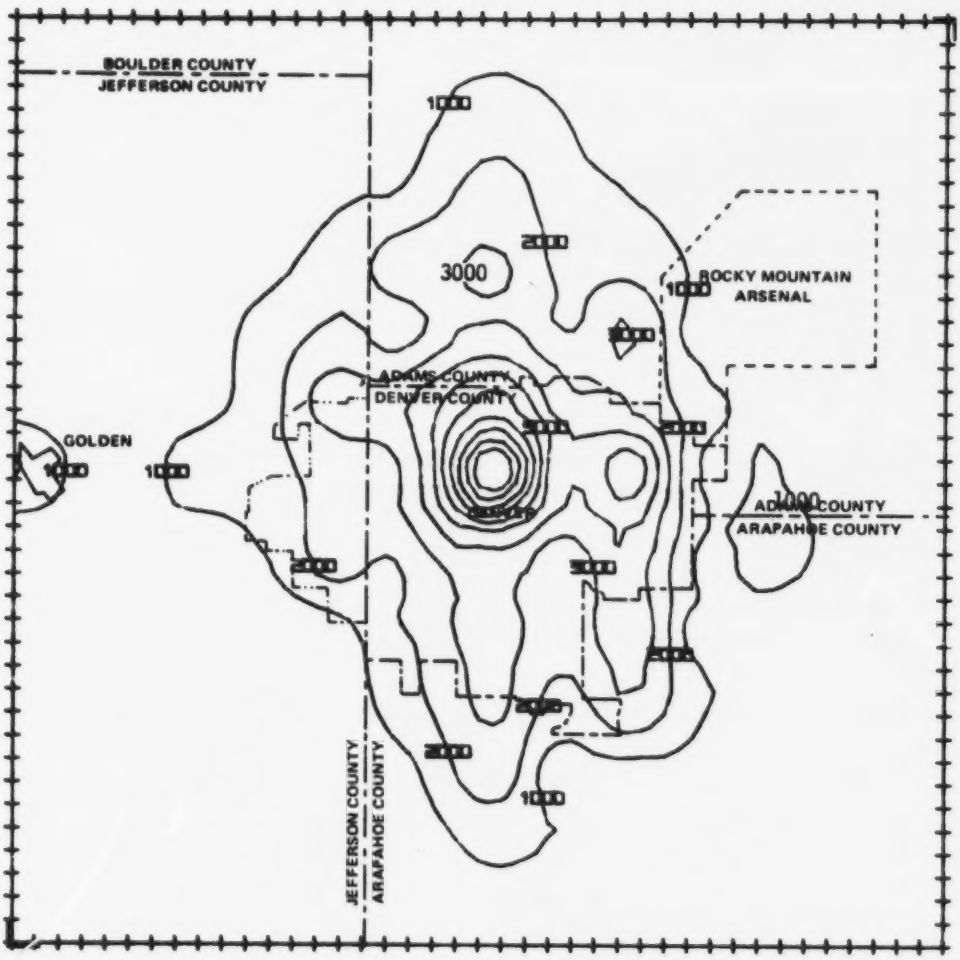


Fig. A-1 Sample Isopleth
Isopleth No. Den. 1

City Denver	Year 1970	Strategy Uncontrolled
Pollutant CO	Case 2	Time Period 8 hour Total
Units $mg/m^3 \times 10^3$	Federal Standard 10 mg/m^3	

EMISSION FACTOR CALCULATIONS

The equation for calculating emission factors is shown below:[1]

$$e_{np} = \sum_{i=n-12}^{n+1} ci\ di\ mi\ si$$

where,

e_{np} = emission factor in grams per vehicle mile for calendar year n and pollutant p,

c_i = the 1975 Federal test procedure emission rate for pollut nt p (grams/mile) for the i^{th} model year, at low mileage

d_i = the controlled vehicle pollutant p emission deterioration factor for the i^{th} model year at calendar year n,

m_i = the weighted annual travel of the i^{th} model year during calendar year n (The determination of this variable involves the use of the vehicle model year distribution),

s_i = the weighted speed adjustment factor for the i^{th} model year vehicles.

c_i is based on a recent study of light duty vehicle exhaust emission rates in six cities. d_i, deterioration factor accounts for the aging or deterioration of emission control devices. m_i, weighted annual mileage is determined as follows,

---

[1] D.S. Kircher and D.P. Armstrong, "An Interim Report on Motor Vehicle Emission Estimation," Environmental Protection Agency, October 1972.

$$mi = \frac{V \times D}{\Sigma V \times D}$$

V = fraction of each model year vehicle in use on December 31 of year

D = average miles driven of each model year vehicle

s_i, speed adjustment factor, varies inversely with average route speed.[1] 1975 and later model years are assumed to have a factor of one.

CALCULATION OF TOTAL EMISSIONS

$$\text{Total Emissions (tons CO/day)} = E = \left[.0011 \left(e_L \, VMT_L + e_H \, VMT_H + e_D \, VMT_D\right)\right] + E_s$$

e = emission factor, gm/mile

VMT = daily vehicles miles traveled x 10^{-3}

Subscrips:

L = light duty vehicle

H = heavy duty vehicle

D = diesel

E_s = Stationary source emissions (all sources not listed above)

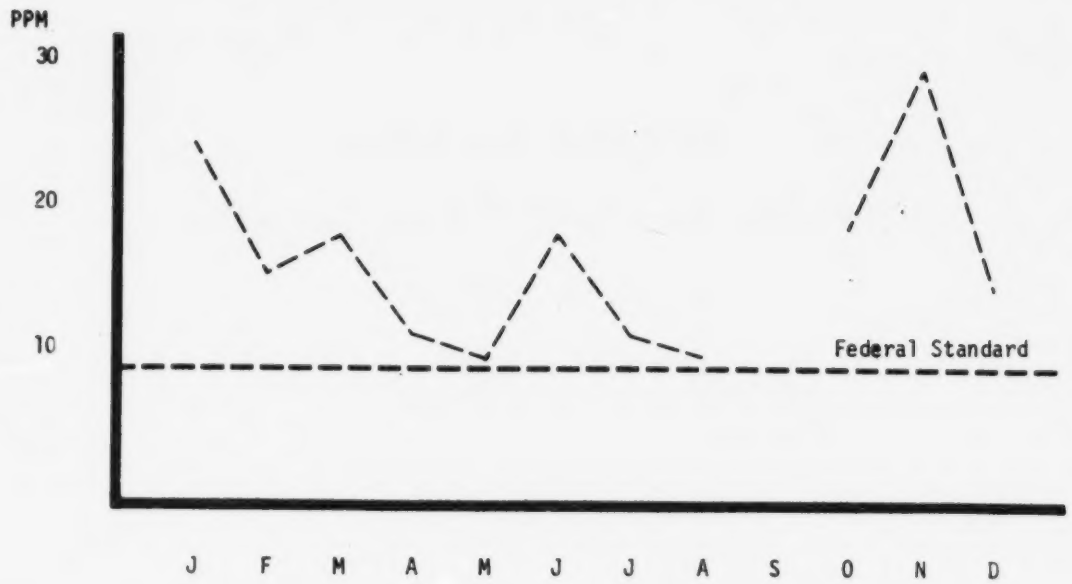


Fig. A-2

CO (Max) eight-hr. monthly ave. (1971)

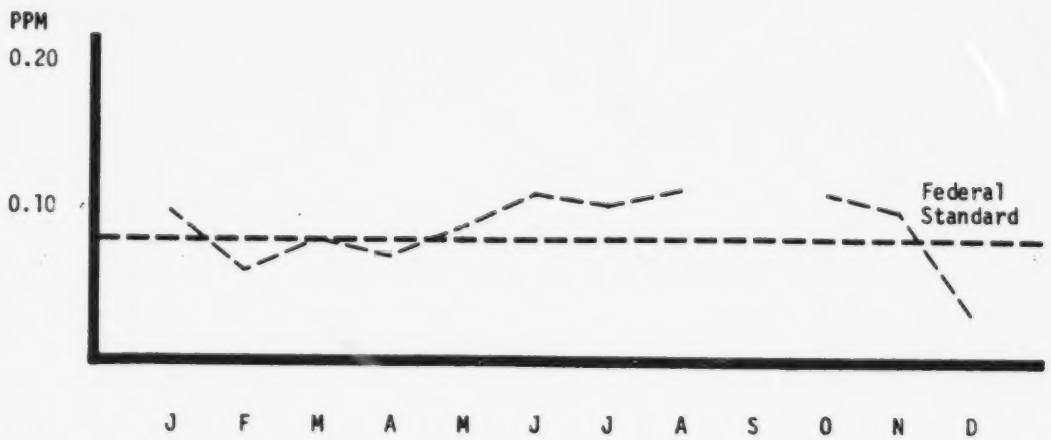


Fig. A-3

Total Oxidants Peak Hr. Monthly Max. (1971)

APPENDIX B
TRANSPORTATION DATA BASE

TRAVEL FORECASTS

In 1970, the Colorado Department of Highways prepared summaries of the total vehicle miles of travel per day for the Denver Region. These data were coded for use in the Six Cities Studies being carried out for Denver and five other metropolitan areas for the Environmental Protection Agency. These summaries were prepared by analysis zone for an average day in 1969. The 1969 summaries were prepared from the program of volume counts made by the Highway Department in that year. At that same time, forecasts of 1990 vehicle miles of travel on an average day were made utilizing travel assignment 1990 origin and other forecasts techniques.

The 1969 and 1990 travel forecasts were distributed by the Consultants to a square-mile grid system which encompassed 625 square miles of the Denver region (See Figure B-1). The area of the grid corresponds approximately to earlier areas defined for transportation and urban planning studies. The area included all of the City and County of Denver and parts of Adams, Arapaho, and Jefferson Counties. The travel distributions were used in air pollution modeling in connection with the Six Cities Studies. For the current studies, it was necessary to update the 1969 data to 1971 travel volumes and then expand them to 1977, the target year. The 625 square mile area was subdivided into control areas to obtain separate totals of travel rules for Denver, and the segments of Adams, Arapaho, and Jefferson Counties included.

In addition a 12 square mile analysis area within the City of Denver was defined as the "Central Area". This 12 square mile area is four miles in height and three miles in width. It lies to the south of 52nd Avenue, one-half mile north of FAI 70 and to the east of FAI 25 as far as Colorado Boulevard.

A three square mile critical analysis area within the Central Area was defined as the "Core". The three square miles encompass the district bounded by Laramir Street on the northwest, 20th Street and 20th Avenue on the north, Logan Street on the east, 13th Avenue on the south, and Speed Boulevard on the west, traditionally defined as the Central Business District in earlier studies.

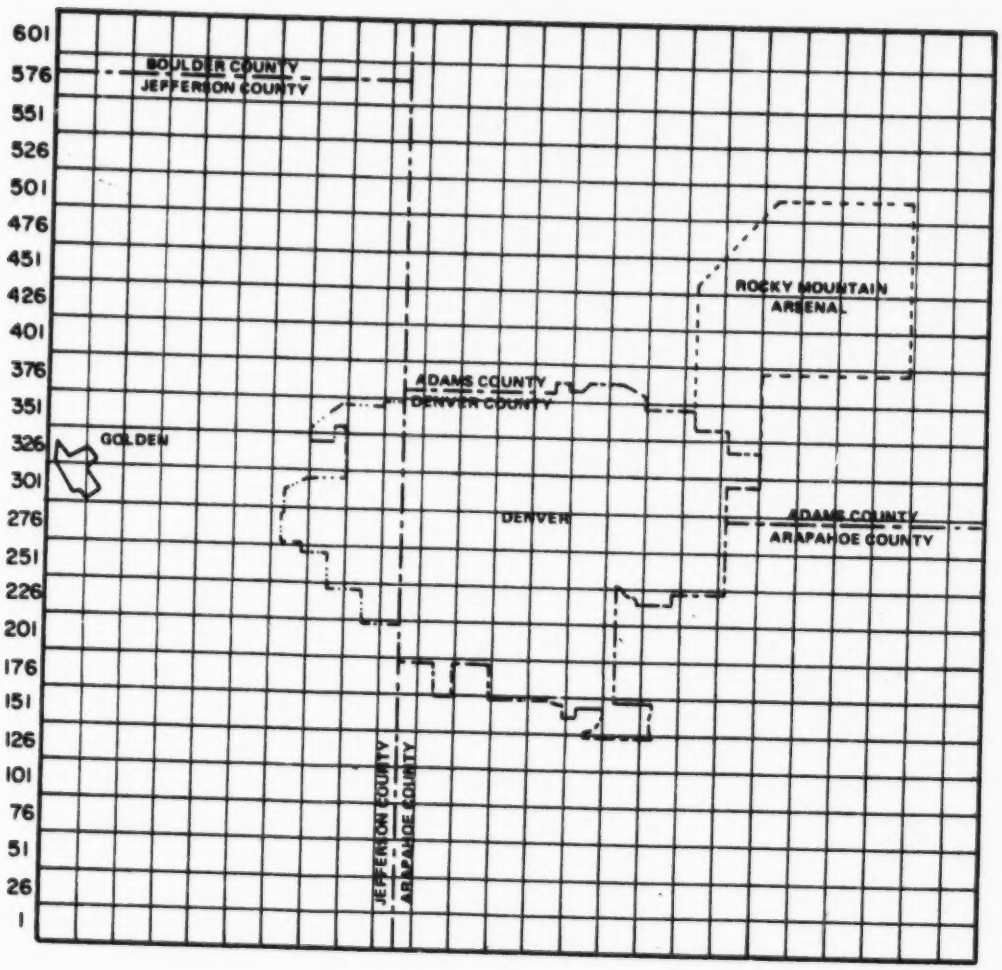


Figure B-1 Denver Grid

In 1971 another comprehensive volume count program was undertaken in the Denver region. Data from this program served as the basis for updating the vehicles miles of travel in the 12 square mile Central Area and the three square mile Core Area.

For the remainder of the City of Denver and the other three counties, 1971 vehicle miles of travel were determined by expansion of the 1969 travel summaries. Volumes in 1965, 1969, and 1971 from the counting program were compared across various screen lines. On the basis of these comparisons, it was determined that the growth rate over the two years had been approximately three percent per year compounded for the City of Denver, five percent per year for Arapaho and Adams Counties and approximately six percent per year for Jefferson County.

The resulting total increase in the vehicle miles of travel within the 625 square mile area was from 10.0 million vehicle miles of travel on an average day in 1969 to 11.4 million vehicle miles of travel on an average day in 1971.

The same screen line analyses were used as a basis for determining future growth rates to 1977. It is estimated that there will be approximately 14,700,000 vehicle miles of travel on an average day in 1977 in the 625 square mile area.

A summary of the 1971 and estimated 1977 vehicle miles of travel for the five major analysis zones in the Denver Metropolitan Area are shownn in the table below.

	1971 Average Day VMT	1977 Average Day VMT
City and County of Denver	6,000,000	7,000,000
Adams County (within grid)	1,750,000	2,700,000
Arapaho County (within grid)	2,600,000	3,600,000
Jefferson County (within grid)	1,050,000	1,400,000
TOTAL	11,400,000	14,700,000
Central Area (12 square miles)	1,650,000	1,850,000
Core Area (3 square miles)	560,000	610,000

For the 12 square mile Central Area, historical volume count data indicated that vehicular travel was growing at a rate of approximately 1.5 percent per year compounded in the lower part of the Central Area which included the Central Business District to approximately three percent per year compounded in the northern part of the area.

Application of these growth rates to individual square miles indicated that total travel within the 12 square mile Central Area would increase from approximately 1,650,000 vehicle miles of travel on an average day in 1971 to 1,850,000 on an average day in 1977. Total travel witnin the Core Area three square miles would increase from approximately 560,000 vehicle miles of travel on an average day in 1971 to 610,000 in 1977.

While the three square mile area designated as the Core represents only one-fourth of the land in the Central Area, the Core generates approximately one-third of the total vehicle miles of travel in the 12 square miles.

Table B-1

VEHICLE MILES OF TRAVEL (VMT)
FOR THE CENTRAL AREA
DENVER, COLORADO

Grid Number	1971 by Computer by Others	1971 by DCCO(1)	1977 by Computer by Others	1977 by DCCO(2)
287	135,800	200,000	151,700	220,000
288	330,200	240,000	263,800	260,000
289	213,900	180,000	263,900	196,000
312	227,400	210,000	55,100	230,000
313	163,500	140,000	53,300	154,000
314	126,200	70,000	158,100	84,000
338	116,600	200,000	136,100	220,000
339	87,300	50,000	112,800	60,000
340	56,600	35,000	37,600	42,000
364	108,800	100,000	138,600	120,000
365	81,600	100,000	100,700	120,000
366	75,300	100,000	53,800	120,000
Totals	1,723,200	1,625,000	1,525,500	1,826,000
		Say 1,650,000		Say 1,850,000

(1) The twelve (12) square miles calculated from Denver Metropolitan Area Traffic Map for the year 1971.

(2) Projected by 1.5 percent and 3.0 percent per year compounded as appropriate for each square mile.

Table B-2

VEHICLE MILES OF TRAVEL (VMT)
FOR CORE AREA

DENVER, COLORADO

Grid Number	1971 by Computer by Others	1971 by DCCO(1)	1977 by Computer by Others	1977 by DCCO(
288	330,200	240,000	263,800	260,000
289	213,900	180,000	263,900	196,000
313	163,500	140,000	53,300	154,000
Total	707,600	560,000	581,000	610,000

(1) The three square miles calculated from Denver Metropolitan Area Traffic Volume Map for the year 1971.

(2) Projected by 1.5 percent per year compounded.

Table B-3

DE LEUW, CATHER & COMPANY CALCULATIONS AND FORECAST
OF VEHICLE MILES OF TRAVEL (VMT)
FOR THE FIVE ZONES IN THE DENVER METROPOLITAN AREA
FOR THE YEARS 1971 AND 1977

Zone Number	1971 Vehicle Miles of Travel	1977 Vehicle Miles of Travel
1	1,050,000	1,400,000
2	2,600,000	3,600,000
3	4,350,000	5,150,000
4	1,650,000	1,850,000
5	1,750,000	2,700,000
Total	11,400,000	14,700,000

APPENDIX C

COLORADO AIR POLLUTION CONTROL COMMISSION TRANSPORTATION PLANNING ADVISORY COMMITTEE - RECOMMENDED PHASED STRATEGY ELEMENTS (ROUGH DRAFT 11-30-72)

C-1

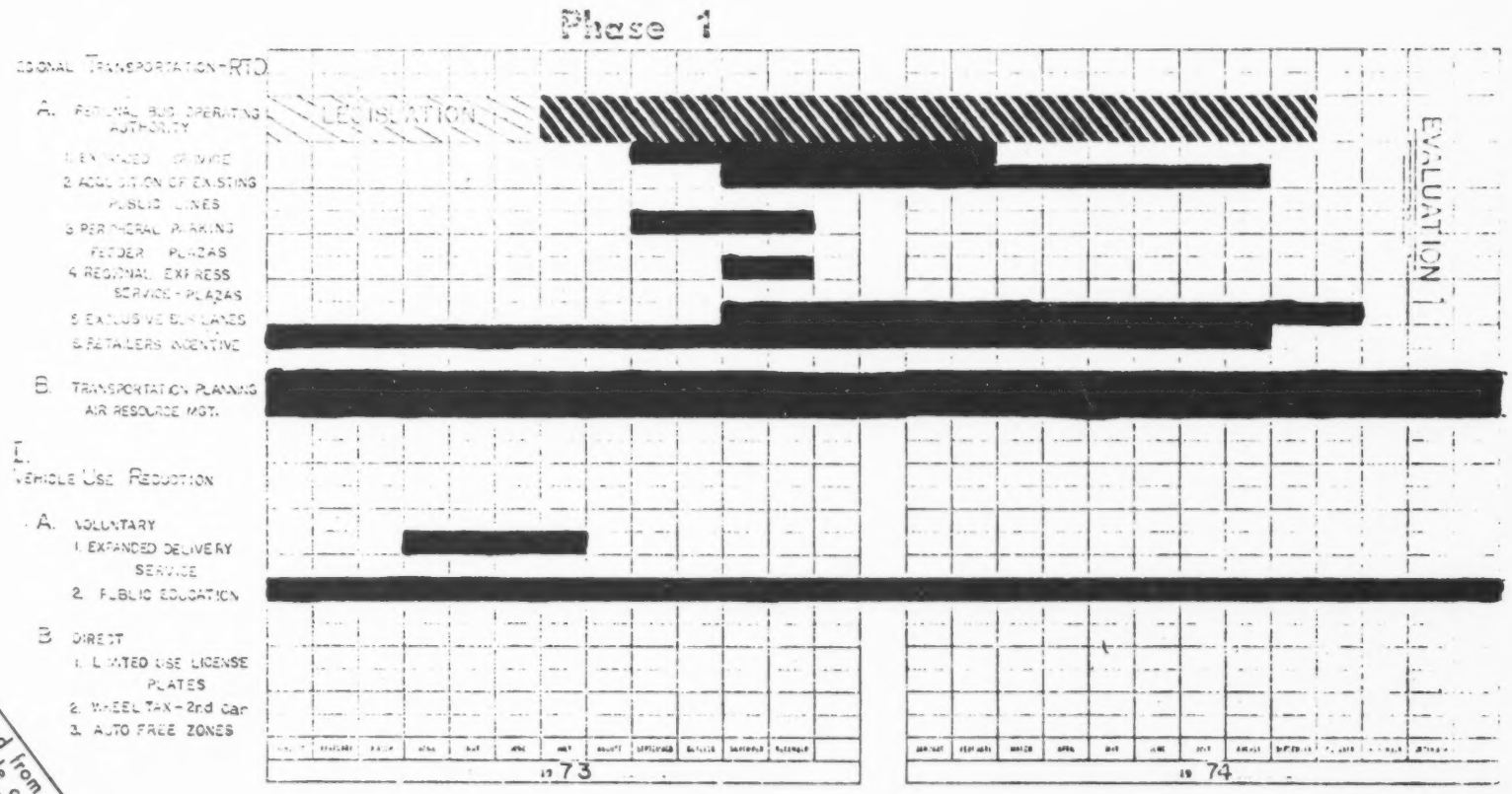


Fig. C-1. Rough Draft of Phase 1 of Colorado Air Pollution Control Commission Transportation Planning Advisory Committee Recommendations

Reproduced from best available copy.

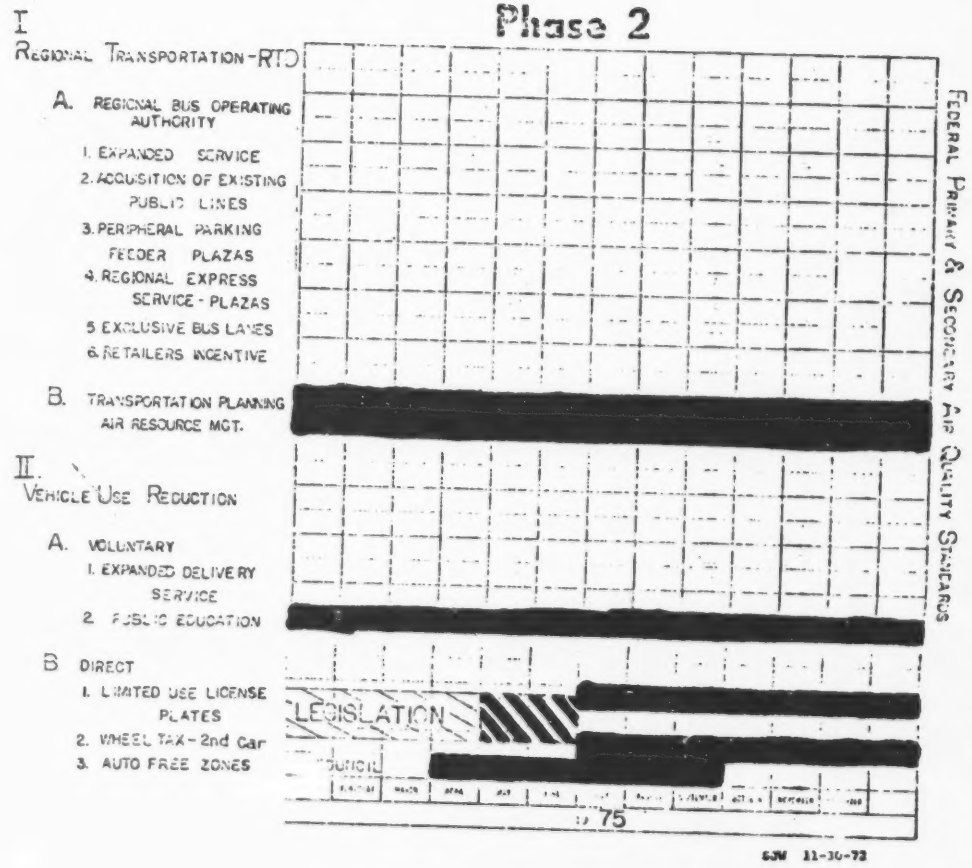
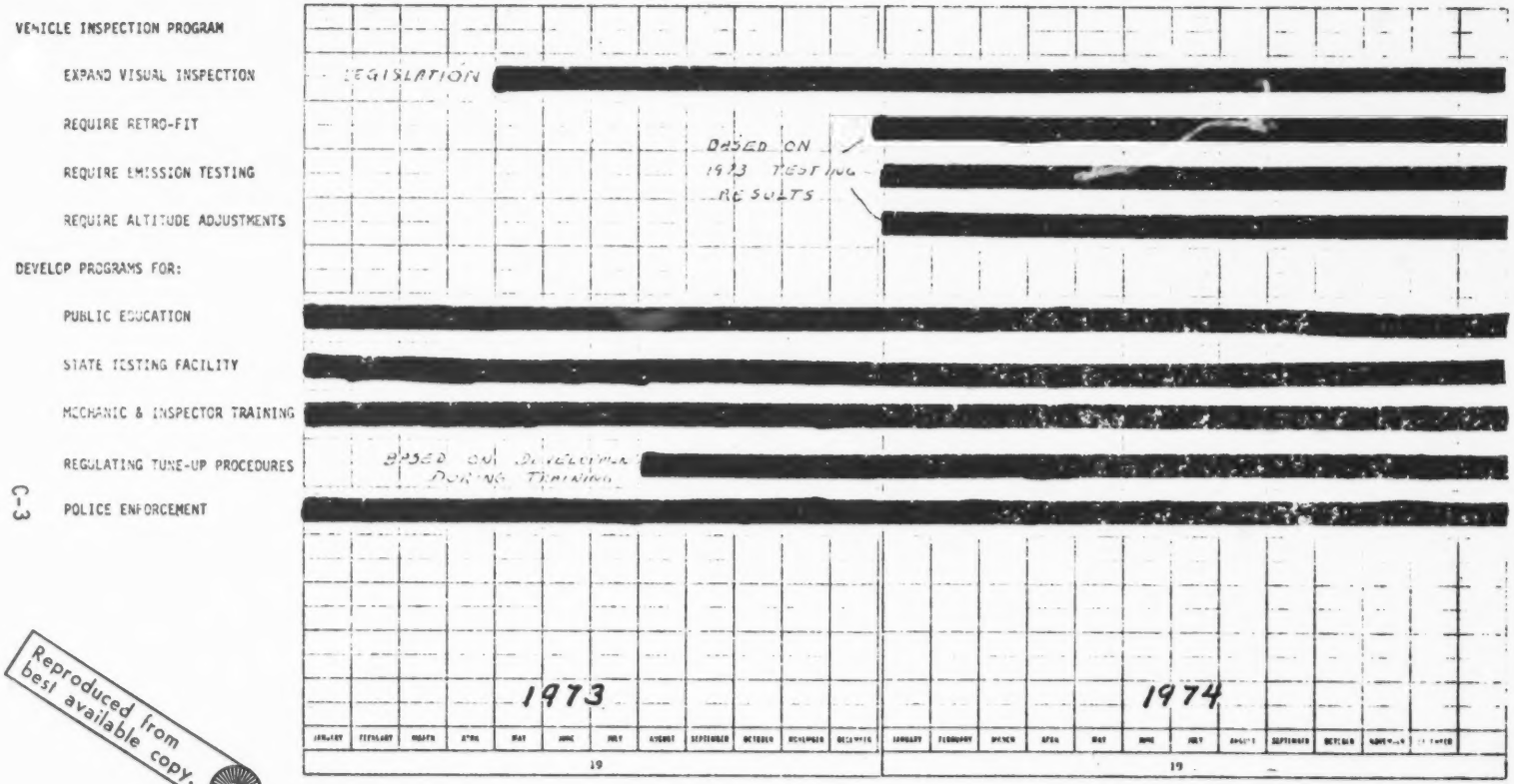


Fig. C-2 Rough Draft of Phase 2

Reproduced from best available copy.



Reproduced from best available copy.

Fig. C-3 Rough Draft of Phase 1 section III

APPENDIX D
DATA AND DOCUMENT LIST

BIBLIOGRAPHY OF TRAFFIC DATA REFERENCES
DENVER, COLORADO

Alan M. Voorhees & Associates, Inc. Parking in Downtown Denver. A Study of the Off-Street Parking Needs of the Central Business District Core. Prepared for the City and County of Denver. Denver, Colorado. April 1971.

W. C. Gilman & Co., Inc. Denver Transit Study. Prepared for the City and County of Denver. Denver, Colorado. October 1970.

Nelson, Haley, Patterson, andQQuirk Ecodesign. Advanced Urban Transit Technology Study. Prepared for the Regional Transportation District. Denver, Colorado. October 1972.

Morris, John. An Interim Transportation Plan. For Plan Metro Denver. Denver, Colorado. March 1972.

American Trasit Association. Monthly Transit Traffic. Denver, Colorado. Various months.

State Department of Highways, Division of Highways, State of Colorado. Colorado Traffic Volume Study. Colorado. 1968.

_____. Traffic Volume on Urban Freeways in Colorado. Three Volumes. Colorado. 1966, 1968, and 1971.

Transportation Planning Advisory Committee. Report and Recommendations. Prepared for the Colorado Air Pollution Control Commission. Colorado. October 4, 1972.

Automotive Testing Laboratories, Inc. Vehicle Age Distribution Data. June 1972.

INSTITUTE OF PUBLIC ADMINISTRATION, TEKNEKON, INC. & TRW INC.:

Evaluating Transportation Controls to Reduce Motor Vehicle Emissions in Major Metropolitan Areas - An Interim Report. Environmental Protection Agency, March 1972.

STATE OF COLORADO:

Colorado Air Quality Implementation Plan. Department of Health, January 1972.

NORTHROP CORPORATION:

Analysis of Vehicle Emission Inspection Programs. California Air Resources Board
Vehicle Emission Inspection and Control Program - Summary, Vol. I, November 1972.

REGION VIII AIR QUALITY BRANCH STAFF:

A Report to the Transportation Planning Advisory Committee, E.P.A.

COLORADO DEPARTMENT OF HEALTH:

"Air Pollution Model for Metro Denver" - Grant Proposal, November 1972.
"Objective of Northrop Study in Colorado" August 1972.
"Discussion Before Chamber of Commerce" September 1972.
"Report to Transportation Planning Advisory Committee" August, 1972
"Proposed Colorado Program for Motor Vehicle Emissions" November 1972.

COLORADO AIR POLLUTION CONTROL COMMISSION TRANSPORTATION PLANNING ADVISORY COMMITTEE:

"Recommendations Summary Outline" November 1972.

ENVIRONMENTAL PROTECTION AGENCY:

Title 40 - Protection of Environment, October 1972
AP-42 - Compilation of Air Pollutant Emission Factors, February 1972

RIEHL, HERBERT AND DIRK HERKHOF:

Weather Factors in Denver Air Pollution, August 1970

TRW:

Prediction of the Effects of Transportation Controls on Air Quality in Major Metropolitan Areas, November 1972

NATIONAL AEROMETRIC DATA BANK:

1971 Monthly Peak Hour Oxidant and Eight-Hour Carbon Monoxide Air Quality

ARMSTRONG, D. AND D. KIRSCHER:

An Interim Report on Motor Vehicle Emission Estimation - Draft, October 1972.

APPENDIX E
AUTOMOBILE AIR POLLUTION QUESTIONNAIRE

AUTO AIR POLLUTION QUESTIONNAIRE
DENVER METROPOLITAN AREA

The questionnaire shown in Figure E-1 was sent ot a panel of residents of the Denver Metropolitan Area to obtain their views on factors affecting auto air pollution and potential control measures. A total of 204 usable questionnaires were returned. The sample was selected by Consumer Mail Panels to be representative of the population of the area in terms of income level and age. Annual family income (1971) of respondents was:

Less than $8,000	35%
$8,000-$15,000	46%
More than $15,000	19%

Their home locations were distributed as follows throughout the Denver Metropolitan Area:

Location	Number of Respondents	Percent of Total
Denver	98	48
Lakewood	21	9
Arvada	11	5
Longmont	9	4
Boulder	8	4
Evergreen	7	3
Littleton	7	3
Aurora	6	2
Wheatridge	6	2
Englwood	6	2
Other Communities	35	17
	204	100

Each respondent was asked to indicate the number of autos owned in his household. Answers were as follows:

No car	2%
One car	30%
Two cars	50%
Three or more cars	18%

Questionnaire responses were tabulated by income level and car ownership status of each panel member's family. Results of the survey follow with appropriate explanatory notes.

1. All autos made in 1975 and thereafter will be equipped with emmision control devices to reduce air pollution. If in 1975 you owned a car built before that year, how would you feel about a law requiring you to put emission control equipment which might cost $200 on your car? ("X" BELOW)

2. How would you feel about this law if the cost was reduced by government subsidy to about $50? ("X" BELOW)

Feeling Toward Law:	(165R)* 1. Cost $200	(201R) 2. Cost $50
Very much in favor of law..	10.3%	49.8%
Somewhat in favor of law...	20.6	23.4
Somewhat against law.....	15.2	11.4
Very much against law.....	53.9	15.4

3a. Even cars properly equipped with emmision control equipment might still pollute the air if the equipment was not properly maintained. How would you feel about a law requiring periodic inspection of the emission control system to assure that it was working properly? ("X" ONE ONLY)

Very much in favor of law	Somewhat in favor of law	Somewhat against law	Very much against law
59.1%	26.1%	8.4%	6.4%

3b. Assuming you had to have your car inspected at least once a year, what would you consider a reasonable cost for the inspection? (WRITE IN AMOUNT)

$ 4.58 (mean)

Five percent of the respondents answered "nothing" to this question. The most frequent response (29.1%) was $2.00, followed by 21.4 percent of the panel who answered $5.00 and 18.9 percent felt that $1.00 was an appropriate charge. The following is a tabulation of the mean value by car ownership status of the panel member's family.

No car	$32.83
One car	4.46
Two cars	3.36
Three or more cars	5.28

* Indicates number of respondents. (165R) = 165 respondents.

3c. **Assuming you had to have your car inspected at least once a year, where do you think the inspection should be made? ("X" ONE ONLY)**

At state-operated inspection centers.....	35.8%
At city-operated inspection centers.....	7.8
At local service stations or garages.....	52.5
At some other place (Specify):	3.9

The "other" responses to this question were varied. A few members of the panel suggested that inspection should be accomplished and supervised by the State at various locations.

4a. Even if all autos were equipped with properly maintained emission control systems, some cities might still have auto air pollution problems due to the large number of cars either on the streets at the same time or concentrated in particular areas. Listed below are several possible ways to reduce pollution under one or both of these conditions. Please tell me how you feel about each of these proposals. ("X" ONE ON EACH LINE)

Proposal	To Me This Plan Is: Very Acceptable (+2)	Somewhat Acceptable (+1)	Neither Acceptable Nor Unacceptable (0)	Somewhat Unacceptable (-1)	Very Unacceptable (-2)
a. Gasoline rationing	2.9	6.9	6.4	12.7	▲ 71.1
b. Very high ($500) registration fee per auto	0.0	1.0	5.5	7.0	▲ 86.6
c. Very high ($500) registration fee per auto but only for the second, third, etc., auto	4.0	10.0	7.0	19.9	▲ 59.2
d. Prohibit traffic and parking in central business districts	33.3	▲ 30.4	8.8	16.7	10.8
e. A tax on all day parking in central business districts	18.2	27.1	12.3	▲ 12.3	30.0
f. A tax on parking in central business districts regardless of whether a person parked only one hour or all day	10.0	15.0	14.5	▲ 18.5	42.0
g. Tolls on exit ramps of major freeways and expressways	2.5	5.4	13.9	18.8	▲ 59.4
h. Tolls on exit ramps of major freeways and expressways but only when traffic was heavy	3.5	9.4	8.9	17.8	▲ 60.4
i. Restrictions on non-essential auto travel during times of high pollution by issuance of special license plates or vehicle stickers	13.3	27.6	9.4	▲ 12.3	37.4
j. Turn some existing lanes into "bus only" and "car pool only" lanes on major expressways and streets	34.8	▲ 26.5	10.8	9.3	18.6

▲- Indicates the weighted means for each answer.

4b. Which of the proposals listed above would be the most acceptable? (Give Letter:) d - 35.0%
j - 34.0%

4c. Which would be most unacceptable? ..... (Give Letter:) b - 53.8%
a - 32.7%

QUESTIONS 5-8 ASK FOR INFORMATION RELATING TO OTHER HOUSEHOLD MEMBERS. CONSULT THEM, IF NECESSARY, FOR THE ANSWERS.

5a. How often do the various members of your household travel by public transportation? (For example, by bus, subway, or commuter train.)

	Husband	Wife	Children (Over 16 Years Old)
Three or more times a week.	1.6%	2.0%	5.4%
One or two times a week.....	1.6	3.0	1.8
Once a month.....	3.8	5.0	2.7
Once every three months	2.7	13.4	1.8
Never	86.8	76.6	49.0
No household member	3.3	0.0	39.3

5b. Please rate each household member's reason for using public transportation. (Rate the most important reason "1", the next most important "2", the next "3", etc. If a household member never uses public transportation, "X" the "never use" box at the bottom of the list.)

5c. Please rate each household member's reasons for traveling by auto. Follow the same procedure as in Question 5b. (WRITE IN BELOW UNDER 5c)

CONCENSUS RATING

Reasons	5b. Public Transportation			5c. Auto Transportation		
	Husband	Wife	Children (Over 16 Years Old)	Husband	Wife	Children (Over 16 Years Old
a. Cheaper				7	6	7
b. Faster				3	3	3
c. More comfortable				5	5	6
d. Safer for passenger				8	8	8
e. Less congested				6	6	4
f. More available				1	1	2
g. More flexible (I can come and go as I please)	SEE COMMENTS			2	2	1
h. More relaxing (able to read while traveling)				----NOT APPLICABLE-----		
i. Need car during the day				4	4	5
j. I do not have a driver's license				----NOT APPLICABLE-----		
k. Car is not available when I need it				----NOT APPLICABLE-----		
l. Other (Specify): _____				SEE COMMENTS		
m. Never use ("X" Box)	160/178	155/202	55/68	3/178	9/202	13/68

Comment on Question 5b

There were too few responses to draw meaningful conclusions from this question.

Comment on Question 5c

Respondents indicated that one of the main reasons for driving was lack of mass transit near their residence.

5d. **Again, consulting other members of your household, please rate in order of effectiveness which items below you feel would be most effective in encouraging the use of public transporation. (Rate the most effective item a "1", the next most effective "2", the next "3", etc.)**

Items:	CONCENSUS RATING Husband	Wife	Children (Over 16 Years Old)
Cleaner and newer vehicles..	7	8	8
Faster travel	3	3	2
Air-conditioned vehicles	9	9	9
More frequent service	1	1	1
Lower fares	5	4	3
Parking facilities at stops or stations	4	5	5
Shelters against bad weather at stops or stations.....	6	6	6
Better security to assure personal safety.....	7	7	7
More conveniently located stops and stations	2	2	4

Other (Specify):

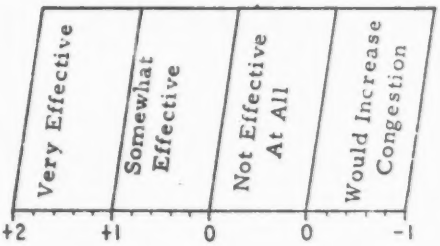
6a. How would you or other household members feel about traveling to and from work in a car pool? ("X" ONE ONLY)

Very interested	19.4%
Somewhat interested	31.1
Not at all interested	32.7
Already in car pool	6.1
Do not travel to and from work by car	10.7

6b. If it became necessary to restrict the number of cars on expressways and streets in order to reduce pollution and car pools became necessary, how difficult do you think it would be to get into one an existing one or organize one amongst your friends, neighbors and/or work associates. ("X" ONE ONLY)

Extremely difficult	31.3%
Very difficult	11.3
Somewhat difficult	28.1
Somewhat easy	14.4
Very easy	7.2
Extremely easy	2.1
Already in car pool	5.6

7. One of the major causes of areas of high pollution is traffic congestion. Pollution could be reduced if traffic congestion and stop-and-go traffic was reduced. Listed below are several ideas for reducing traffic congestion. Please tell me how effective you think each of these ideas would be in reducing congestion and pollution. ("X" ONE BOX FOR EACH IDEA)



Idea:				
a. Prohibit parking, loading and unloading on busy streets	49.0 ▲	42.9	6.1	2.0
b. Increase the number of one-way streets	28.1 ▲	53.6	17.3	1.0
c. Establish reversible lanes on busy streets to be used during rush hours	19.8	43.1 ▲	17.3	19.8
d. Prohibit turns at busy intersections during rush hours	38.5	34.4 ▲	18.5	8.7
e. Widen major streets	40.2 ▲	37.6	17.5	4.8
f. Widen major streets at intersections only	6.8	43.7 ▲	35.3	14.2
g. Provide pedestrian underpasses and/or overpasses	42.6 ▲	38.1	18.3	1.0
h. Improve timing of traffic signals	67.7 ▲	27.7	4.6	0.0
i. Increase the number and frequency of radio traffic reports	13.0	59.6 ▲	25.9	1.6
j. Turn some existing lanes into "bus only" and "car pool only" lanes on express-ways and busy streets	34.4	43.1 ▲	12.8	9.7

Your ideas (Please List):

Several comments and ideas were expressed with regard to the above question. Some panel members feel that mass transit will solve much of the pollution problem. Others thought that if the core area, or downtown, was made a vehicle-free zone, it would help decrease pollution and improve pedestrian circulation.

Reproduced from best available copy.

▲- Indicates the weighted mean for each answer.

8. Since traffic congestion is most severe at times when people are going to or coming from work, one alternative for reducing congestion would be to have people start and stop work at different times of the day. That is, some people would start work at 5:00 AM and quit at 2:00 PM, others would work from 7:00 AM to 4:00 PM, others from 10:00 AM to 7:00 PM, etc. How do you feel about this idea? ("X" ONE ONLY)

Very much in favor.....	33.3%
Somewhat in favor.....	31.3
Indifferent	15.7
Somewhat opposed.....	12.1
Very much opposed.....	7.6

9a. Please record the model year of each car owned in your household. (WRITE IN BELOW UNDER 9a)

9b. Please estimate the number of miles each car was driven in the last year. (WRITE IN NUMBER OF MILES UNDER 9b BELOW)

9c. For each car, please estimate what percentage of last year's mileage was accounted for by driving outside your local metropolitan area. (For example, vacation, business trips, short weekend trips, etc.) (WRITE IN BELOW UNDER 9c)

	9a. Model Year	9b. Last Year's Mileage	9c. Percentage of Mileage Outside Local Area
Car #1	1969	10,935	29
Car #2	1967	9,056	27
Car #3	1966	7,279	26
Car #4	1966	4,500	21

9d. How many licensed drivers are there in your household? (WRITE IN)

Number of Licensed Drivers: 2.1 (Avg.)

9e. If better public transportation were available, would you consider disposing of any of the cars you own?

Yes	11.2%
Maybe	22.4
No	66.4

9f. How many? (WRITE IN) 1.1 cars

10a. Overall, how serious a problem do you think auto air pollution is in your city? ("X" ONE BOX UNDER 10a BELOW)

10b. Overall, how serious a problem do you think auto air pollution is nationwide? ("X" ONE BOX UNDER 10b BELOW)

	10a. City	10b. Nationwide
Very serious problem	39.3%	55.1%
Serious problem	29.9	39.4
Slightly serious problem...	24.4	4.5
No problem at all	6.4	1.0

11. **If you have any views or comments regarding any question or idea, please record them:**

Fourty-seven respondents (23 percent of the panel) added comments at the end of the questionnaire. Fifty percent of the comments were in favor of a better mass transit system for the area to help reduce the need for private cars. Twenty percent felt that older cars, buses and trucks contribute more to the pollution problem than cars. The remainder thought that if laws were enforced to reduce industrial pollution, the problem would be solved.

FIGURE

CONSUMER MAIL PANELS
323 SOUTH FRANKLIN STREET · CHICAGO, ILLINOIS 60606

(2-C796)

Dear Panel Member,

Today, I am sending you a questionnaire which I consider both exciting and interesting. Hopefully, you will too. This questionnaire deals with the important problem of air pollution caused by automobiles.

As you know, autos are a major source of air pollution—especially in metropolitan areas. You probably have read in newspapers or magazines that auto manufacturers are being required to make changes in their cars that will reduce the amount of pollutants coming out of cars. This will be particularly true for cars manufactured in 1975 and thereafter.

Many pollution experts believe, however, that despite these new federal regulations on auto air pollution, other ways will have to be found to further reduce pollution caused by cars. The purpose of this questionnaire is to obtain your reaction to these new auto pollution control ideas being suggested by the experts. In answering some questions, you will probably have to consult other members of your family to get their ideas and reactions. I am sorry if this is inconvenient, but I am sure you will agree that the importance of solving pollution problems is worth making every reasonable effort.

As always, please check each of your answers after you have completed the questionnaire. Then return it to me in the enclosed postage-paid envelope. If you have any additional comments, please write them on the lines provided in Question 11.

Cordially,

CONSUMER MAIL PANELS

(2-C796)

AUTO AIR POLLUTION QUESTIONNAIRE

1. All autos made in 1975 and thereafter will be equipped with emmision control devices to reduce air pollution. If in 1975 you owned a car built before that year, how would you feel about a law requiring you to put emission control equipment which might cost $200 on your car? ("X" BELOW) ☐ 13

2. How would you feel about this law if the cost was reduced by government subsidy to about $50? ("X" BELOW) 14-16 Open

Feeling Toward Law:	1. Cost $200	2. Cost $50
Very much in favor of law . .	☐1	☐1
Somewhat in favor of law . . .	☐2 (17)	☐2 (18)
Somewhat against law	☐3	☐3
Very much against law	☐4	☐4

3a. Even cars properly equipped with emmision control equipment might still pollute the air if the equipment was not properly maintained. How would you feel about a law requiring periodic inspection of the emission control system to assure that it was working properly? ("X" ONE ONLY)

Very much in favor of law ☐1 | Somewhat in favor of law ☐2 | Somewhat against law ☐3 | Very much against law ☐4 — 19

3b. Assuming you had to have your car inspected at least once a year, what would you consider a reasonable cost for the inspection? (WRITE IN AMOUNT)

$_____ 20 ☐☐ 21

3c. Assuming you had to have your car inspected at least once a year, where do you think the inspection should be made? ("X" ONE ONLY)

At state-operated inspection centers . ☐1
At city-operated inspection centers. . ☐2
At local service stations or garages . ☐3
At some other place (Specify): _____ ☐4 — 22

4a. Even if all autos were equipped with properly maintained emission control systems, some cities might still have auto air pollution problems due to the large number of cars either on the streets at the same time or concentrated in particular areas. Listed below are several possible ways to reduce pollution under one or both of these conditions. Please tell me how you feel about each of these proposals. ("X" ONE ON EACH LINE)

Proposal:	To Me This Plan Is: Very Acceptable	Somewhat Acceptable	Neither Acceptable Nor Unacceptable	Somewhat Unacceptable	Very Unacceptable	
a. Gasoline rationing	☐1	☐2	☐3	☐4	☐5	23
b. Very high ($500) registration fee per auto.	☐1	☐2	☐3	☐4	☐5	24
c. Very high ($500) registration fee per auto but only for the second, third, etc., auto.	☐1	☐2	☐3	☐4	☐5	25
d. Prohibit traffic and parking in central business districts	☐1	☐2	☐3	☐4	☐5	26
e. A tax on all day parking in central business districts . .	☐1	☐2	☐3	☐4	☐5	27
f. A tax on parking in central business districts regardless of whether a person parked only one hour or all day	☐1	☐2	☐3	☐4	☐5	28
g. Tolls on exit ramps of major freeways and expressways	☐1	☐2	☐3	☐4	☐5	29
h. Tolls on exit ramps of major freeways and expressways but only when traffic was heavy.	☐1	☐2	☐3	☐4	☐5	30
i. Restrictions on non-essential auto travel during times of high pollution by issuance of special license plates or vehicle stickers	☐1	☐2	☐3	☐4	☐5	31
j. Turn some existing lanes into "bus only" and "car pool only" lanes on major expressways and streets. . . .	☐1	☐2	☐3	☐4	☐5	32

4b. Which of the proposals listed above would be the most acceptable? (Give Letter)_____ ☐ 33

4c. Which would be most unacceptable? . . . . . (Give Letter)_____ ☐ 34

FIGURE (CONT'D.)

(2-C796)

QUESTIONS 5-8 ASK FOR INFORMATION RELATING TO OTHER HOUSEHOLD MEMBERS. CONSULT THEM, IF NECESSARY, FOR THE ANSWERS.

5a. How often do the various members of your household travel by public transportation? (For example, by bus, subway, or commuter train.)

	Husband	Wife	Children (Over 16 Years Old)
Three or more times a week	...☐1	...☐1	...☐1
One or two times a week	...☐2	...☐2	...☐2
Once a month	...☐3 (35)	...☐3 (36)	...☐3 (37)
Once every three months	...☐4	...☐4	...☐4
Never	...☐5	...☐5	...☐5
No household member	...☐6	...☐6	...☐6

5b. Please rate each household member's reason for using public transportation. (Rate the most important reason "1", the next most important "2", the next "3", etc. If a household member never uses public transportation, "X" the "never use" box at the bottom of the list.)

5c. Please rate each household member's reasons for traveling by auto. Follow the same procedure as in Question 5b. (WRITE IN BELOW UNDER 5c)

Reasons:	5b. Public Transportation: Husband	Wife	Children (Over 16 Years Old)	5c. Auto Transportation: Husband	Wife	Children (Over 16 Years Old)
a. Cheaper	___(38)	___(39)	___(40)	___(41)	___(42)	___(43)
b. Faster	___(44)	___(45)	___(46)	___(47)	___(48)	___(49)
c. More comfortable	___(50)	___(51)	___(52)	___(53)	___(54)	___(55)
d. Safer for passenger	___(56)	___(57)	___(58)	___(59)	___(60)	___(61) (74-78 open)
e. Less congested	___(62)	___(63)	___(64)	___(65)	___(66)	___(67) 79-☐☐80
f. More available	___(68)	___(69)	___(70)	___(71)	___(72)	___(73) Cd. 2
g. More flexible (I can come and go as I please)	___(15)	___(16)	___(17)	___(18)	___(19)	___(20) Dup. 1-14
h. More relaxing (able to read while traveling)	___(21)	___(22)	___(23)	----- (Not Applicable) -----		
i. Need car during the day	----- (Not Applicable) -----			___(24)	___(25)	___(26)
j. I do not have a driver's license	___(27)	___(28)	___(29)	----- (Not Applicable) -----		
k. Car is not available when I need it	___(30)	___(31)	___(32)	----- (Not Applicable) -----		
l. Other (Specify): _____	___(33)	___(34)	___(35)	___(36)	___(37)	___(38)
m. Never use ("X" Box)	☐1	☐2	☐3 (39)	☐1	☐2	☐3 (40)

5d. Again, consulting other members of your household, please rate in order of effectiveness which items below you feel would be most effective in encouraging the use of public transportation: (Rate the most effective item a "1", the next most effective "2", the next "3", etc.)

Items:	Husband	Wife	Children (Over 16 Years Old)
Cleaner and newer vehicles	___(41)	___(42)	___(43)
Faster travel	___(44)	___(45)	___(46)
Air-conditioned vehicles	___(47)	___(48)	___(49)
More frequent service	___(50)	___(51)	___(52)
Lower fares	___(53)	___(54)	___(55)
Parking facilities at stops or stations	___(56)	___(57)	___(58)
Shelters against bad weather at stops or stations	___(59)	___(60)	___(61)
Better security to assure personal safety	___(62)	___(63)	___(64)
More conveniently located stops or stations	___(65)	___(66)	___(67)
Other (Specify): _____	___(68)	___(69)	___(70) (71-78 open) 79-☐☐80

FIGURE (CONT'D.)

(2-C796)

Cd. 3
Dup. 1-14

6a. How would you or other household members feel about travelling to and from work in a car pool? ("X" ONE ONLY)

- Very interested . . . . . ☐1
- Somewhat interested . . . . ☐2
- Not at all interested . . . . ☐3
- Already in car pool. . . . . ☐4
- Do not travel to and from work by car. . . . . ☐5

15

6b. If it became necessary to restrict the number of cars on expressways and streets in order to reduce pollution and car pools became necessary, how difficult do you think it would be to get into one an existing one or organize one amongst your friends, neighbors and/or work associates. ("X" ONE ONLY)

- Extremely difficult . . . . . ☐1
- Very difficult . . . . . ☐2
- Somewhat difficult . . . . ☐3
- Somewhat easy . . . . . ☐4
- Very easy. . . . . ☐5
- Extremely easy . . . . . ☐6
- Already in car pool . . . . ☐7

16

7. One of the major causes of areas of high pollution is traffic congestion. Pollution could be reduced if traffic congestion and stop-and-go traffic was reduced. Listed below are several ideas for reducing traffic congestion. Please tell me how effective you think each of these ideas would be in reducing congestion and pollution. ("X" ONE BOX FOR EACH IDEA)

Idea:	Very Effective	Somewhat Effective	Not Effective At All	Would Increase Congestion	
a. Prohibit parking, loading and unloading on busy streets	☐1	☐2	☐3	☐4	17
b. Increase the number of one-way streets.	☐1	☐2	☐3	☐4	18
c. Establish reversible lanes on busy streets to be used during rush hours.	☐1	☐2	☐3	☐4	19
d. Prohibit turns at busy intersections during rush hours .	☐1	☐2	☐3	☐4	20
e. Widen major streets.	☐1	☐2	☐3	☐4	21
f. Widen major streets at intersections only.	☐1	☐2	☐3	☐4	22
g. Provide pedestrian underpasses and/or overpasses . . .	☐1	☐2	☐3	☐4	23
h. Improve timing of traffic signals.	☐1	☐2	☐3	☐4	24
i. Increase the number and frequency of radio traffic reports	☐1	☐2	☐3	☐4	25
j. Turn some existing lanes into "bus only" and "car pool only" lanes on expressways and busy streets	☐1	☐2	☐3	☐4	26
Your ideas (Please List): _____ _____	☐1	☐2	☐3	☐4	27

8. Since traffic congestion is most severe at times when people are going to or coming from work, one alternative for reducing congestion would be to have people start and stop work at different times of the day. That is, some people would start work at 5:00 AM and quit at 2:00 PM, others would work from 7:00 AM to 4:00 PM, others from 10:00 AM to 7:00 PM, etc. How do you feel about this idea? ("X" ONE ONLY)

- Very much in favor . . . . . ☐1
- Somewhat in favor . . . . . ☐2
- Indifferent. . . . . ☐3
- Somewhat opposed . . . . . ☐4
- Very much opposed . . . . . ☐5

28

(PLEASE CONTINUE ON THE NEXT PAGE)

FIGURE

(E-C796)

9a. Please record the model year of each car owned in your household. (WRITE IN BELOW UNDER 9a)

9b. Please estimate the number of miles each car was driven in the last year. (WRITE IN NUMBER OF MILES UNDER 9b BELOW)

9c. For each car, please estimate what percentage of last year's mileage was accounted for by driving outside your local metropolitan area. (For example, vacation, business trips, short weekend trips, etc.) (WRITE IN BELOW UNDER 9c)

	9a. Model Year	9b. Last Year's Mileage	9c. Percentage of Mileage Outside Local Area	
Car #1	____	_____	___%	29 ☐☐☐ 31
Car #2	____	_____	___%	32 ☐☐☐ 34
Car #3	____	_____	___%	35 ☐☐☐ 37
Car #4	____	_____	___%	38 ☐☐☐ 40

9d. How many licensed drivers are there in your household? (WRITE IN)

Number of Licensed Drivers: _____ ☐ 41

9e. If better public transportation were available, would you consider disposing of any of the cars you own?

42 ☐☐ 43

Yes ☐1 → 9f. How many? (WRITE IN) _____ cars

Maybe ☐2 →

No ☐3 →

10a. Overall, how serious a problem do you think auto air pollution is in your city? ("X" ONE BOX UNDER 10a BELOW)

10b. Overall, how serious a problem do you think auto air pollution is nationwide? ("X" ONE BOX UNDER 10b BELOW)

	10a. City		10b. Nationwide	
Very serious problem	☐1	(44)	☐1	(45)
Serious problem	☐2		☐2	
Slightly serious problem	☐3		☐3	
No problem at all	☐4		☐4	

11. If you have any views or comments regarding any question or idea, please record them:

_____

_____

_____

_____

_____

_____

_____

_____

(46-78 open)

79 ☐☐ 80

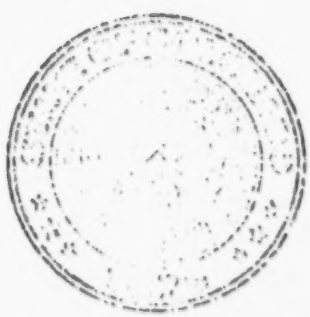
Thank you for your help. Please check your answers and then return the questionnaire to me in the enclosed postage-paid envelope.

APPENDIX F
VEHICLE EMISSION INSPECTION AND CONTROL PROGRAM

VEHICLE EMISSION INSPECTION AND CONTROL PROGRAM

FINAL REPORT

VOLUME I
SUMMARY



GIBBS & HILL, INCORPORATED
A Subsidiary of Raytheon Company

VEHICLE EMISSION INSPECTION AND CONTROL PROGRAM

FINAL REPORT
VOLUME I - SUMMARY

Prepared under Contract Agreement
dated 25 May 1972
with the
State of Colorado
Department of Health

Approved by

R. D. Gafford, Ph. D., Vice President,
Research and Engineering Department

15 November 1972

OLSON LABORATORIES, INCORPORATED
A Subsidiary of Northrop Corporation
500 East Orangethorpe Avenue
Anaheim, California 92801

FOREWORD

The State of Colorado recognizes that the air pollution problem is brought about and influenced by the growing number of citizens and their greater dependence on motorized transportation, increased affluence, more industrial developments, and changing social values. Accordingly, the Colorado legislature, through the Air Pollution Control Act (1970), created the Air Pollution Control Commission and charged it with the responsibility to use all available practical methods to reduce, prevent, and control air pollution throughout the entire state.

The Commission has determined that one of the major contributors to Colorado air pollution is the motor vehicle of which the majority are light-duty passenger automobiles. The Air Quality Implementation Plan for the State of Colorado, developed in accordance with the requirements of the Federal Clean Air Act (1970), identifies several alternative strategies directed at automobile emissions reduction which, in combinations, could assist the State in meeting established Federal air quality criteria.

These strategies include mass transit systems, car pools, limited vehicular traffic patterns, restricted commercial business district parking and/or cruising and staggered work schedules. Each of these is intended to effect a reduction in the daily use of passenger vehicles. Other strategies involve the periodic inspection and maintenance of light duty vehicles and the installation of emission control devices on a retrofit basis. All of these strategies have advantages and disadvantages.

To determine the technical and economic feasibility and the public acceptability of a vehicle emission inspection and control program, the Commission selected the Northrop Corporation to conduct the study after a review of four responses to a request-for-proposal. This investigation was conducted in accordance with the terms specified in the Contract Agreement, dated 25 May 1972, between the State of Colorado, Department of Health, and the Northrop Corporation. The final report is documented in three volumes. Volume I, Summary, briefly describes the study objectives, methodology, findings, conclusions, and recommendations. Volume II, Technical Analysis and Results, describes in detail the analytical tasks and results of the investigation. Volume III, Appendices, contains pertinent data and information used in the investigation.

ACKNOWLEDGMENTS

This final report was prepared for the State of Colorado Department of Health, Division of Air Pollution Control, and for the Commission on Air Pollution Control. The total investigation required 24 weeks of concentrated effort and support involving many organizations, without whose cooperation this contracted study could not have been completed within the established economic and time constraints.

The coordination of various activities, reviews, meetings, and discussions relative to the study was managed by Mr. Lane Kirkpatrick, Technical Secretary of the Air Pollution Control Commission, and his staff.

The Air Pollution Control Division, under the directorship of Dr. Gerald Wood, compiled and analyzed data on Colorado vehicles, estimated future vehicle population growth trends, determined cost elements unique to Colorado, developed computer programs to analyze the Arizona vehicle emissions data, performed emission testing at Alamosa and Denver, and completed many other tasks essential to the conduct of this study.

The Department of Revenue, Division of Motor Vehicles, through Mr. Richard Love, Supervisor of Motor Vehicle Dealers Administration, discussed and provided information concerning the existing vehicle safety inspection program.

The Advisory Committee on Motor Vehicle Emissions, under the chairmanship of Mrs. Iaboyta Garnand, League of Women Voters, and comprised of members from the Colorado legislature, environmental and ecological groups, petroleum retailers, motor vehicle dealers, Legal Aid Society, EPA, Colorado State University, and other interested groups, provided guidance and recommendations on various socio-economic factors. As related to statewide emission control programs, some of the topics discussed were inspection and maintenance financing, low-income vehicle owners, certification of inspectors and service technicians, and consumer protection plans.

The Colorado Automobile Dealers Association assisted in the survey of its members to determine the types of problems current vehicles are experiencing, average costs for typical types of emission-oriented maintenance, in-house availability of emission measurement equipment, and general training and qualification profiles of representative dealer facilities.

The State of Arizona, Department of Health, Division of Air Pollution Control, Vehicular Emissions Control Section, through special arrangements with the Colorado Air Pollution Control Commission, provided the mobile emission test unit and technicians for some emission testing in Colorado. Additionally, through the cooperation of Mr. Arthur Aymar, now Assistant Director of Air Pollution Control, emission test data on several thousand vehicles tested at various altitudes in Arizona were provided.

The U. S. Environmental Protection Agency, Region VIII, through the courtesy of Mr. Dale Wells, provided a preliminary copy of the study report describing a contracted vehicle test project conducted by Automotive Testing Laboratories, Inc. of Aurora, Colorado. The test and service data on a fleet of 75 1968-1972 vehicles were immeasurably helpful in calculating emission profiles and program effectiveness.

Opinion Research of California, under subcontract to Northrop, developed the public opinion questionnaire, selected the samples, performed the survey, compiled the data, and interpreted the results.

SUMMARY

STUDY BACKGROUND

The Colorado legislature, under House Joint Resolution No. 1012, directed the Department of Health to conduct a study for the Air Pollution Control Commission concerning the feasibility and problems of controlling motor vehicle emission through a statewide implementation of an inspection and control program. Many issues were cited in the resolution that need to be investigated and evaluated prior to making any policy decision.

This report documents the study conducted for the Health Department by the Northrop Corporation, in association with its subsidiary Olson Laboratories, Incorporated. It describes the overall methodology, findings, conclusions, and recommendations such that the Department of Health may have sufficient information from which it can derive its recommendations to the Governor and the General Assembly.

GENERAL STUDY OBJECTIVES

The overall study was designed to evaluate the technical and economic feasibility, and public acceptability of a vehicle emission inspection and control program. To facilitate the investigation, the study tasks were defined in such a manner that their completion would provide answers to the following types of questions:

- Is a statewide implementation of vehicle emission inspection and maintenance a viable and practicable program?
- What emission reductions can be achieved through such an implementation?
- What problems would be encountered with urban and rural applications of such a program?
- Would the safety and economical performance of motor vehicles be affected?
- What degree of participation should the State and private sector have in vehicle inspection and maintenance?
- What are the program implementation and operating costs to the State?

- What are the social and economic impacts on the vehicle owner?

- How would the public react to a periodic vehicle emission inspection program?

GENERAL STUDY CONCLUSIONS

Investigation of the technical, economic, and social aspects of a vehicle emission inspection and control program indicate that:

- Mobile sources are responsible, in general, for about 92 percent of the carbon monoxide (CO), 87 percent of the hydrocarbons (HC), and 62 percent of the oxides of nitrogen (NO_x) emitted to the Colorado atmosphere.

  Mobile sources' contribution to Colorado air pollution is relatively the same for each AQCR except Region 8 where it contributes significantly less CO and NO_x.

  Vehicle emissions of HC and CO at Colorado altitudes are significantly higher than at low-altitude cities.

- Periodic vehicle emission inspection coupled with emissions-oriented maintenance is one feasible approach to achieving reductions in emitted HC and CO.

  Key Mode inspection, which involves testing the vehicle under dynamic, simulated road-load conditions using a chassis dynamometer, is more effective than Idle inspection.

  For emissions inspection only, State operated facilities are more cost effective than privately operated facilities.

- For combined vehicle safety and emissions inspection, modifying and updating the current safety inspection program employing private facilities would be more cost effective than establishing new state facilities.

- The private sector should perform emission-oriented maintenance regardless of which sector performs the inspection.

- Installation of emission control systems on pre-1968 vehicles on a retrofit basis appears to be another technically and economically feasible approach to emission reductions. Further testing of selected systems is recommended at various Colorado altitudes.

  The high-altitude modification packages designed by Pontiac Motor Division in Denver appear to be effective in reducing emissions of 1972 GM vehicles. Further testing is recommended on other vehicles at various Colorado altitudes to validate this approach.

- The opinion survey of urban and rural Colorado residents determined that the majority of the residents (72 percent) identify the automobile as the greatest contributor to air pollution.

- Majority of the residents (81 percent) would approve of a vehicle inspection and control program.

- Majority of the residents (83 percent) believe that the programs should be equally applicable to rural and urban residents.

- Majority of the residents (65 percent) feel that all vehicles, regardless of age, should have emission control systems installed.

- Residents were divided on who should conduct emission inspections, with 49 percent favoring private stations, 44 percent favoring state operation, and 7 percent undecided.

- Residents expressed a definite lack of knowledge with respect to the cost of emission-oriented vehicle maintenance. Seventy eight (78) percent did not know what a realistic amount should be.

- Majority of the residents (94 percent) definitely favor the current vehicle safety inspection program.

TECHNICAL FEASIBILITY ANALYSIS

A requirement analysis was conducted that considered current trends in Federal regulations affecting vehicle emissions standards and measurement, the past and current efforts to reduce and control emissions, the effects of vehicle maintenance on emissions, the altitude effects on vehicle emissions and performance, and other related background information needed to formulate the investigation. Two alternative inspection concepts, Idle and Key Mode, were analyzed functionally and operationally to define the requirements in terms of total facility instrumentation and personnel staffing. The requirements for overall program management and administration were also defined. Two facility ownership and operation arrangements were evaluated, State operation and licensed private stations. The general conclusions from this task are that:

- Equipment and technology are presently available to perform vehicle emission inspection and maintenance.

- A statewide network of facilities will require modification to existing equipments to be used for large-scale commercial-grade, high volume inspection.

- The Air Pollution Control Commission and the Air Pollution Control Division have analyzed the GM high altitude compensation concept. Emission test data on several vehicles indicate that significant reductions in HC and CO may be achieved, with NO_x increasing. The concept, which involves carburetor modifications and idle parameter adjustments, would be implemented on a retrofit basis. This study did not investigate the applicability of this concept due to the lack of documentation relative to the experimental design and project. However, further effort is recommended and discussed in subsequent paragraphs on this matter.

EFFECTIVENESS ANALYSIS

To evaluate and compare the alternative inspection and control programs, an effectiveness measure was developed that considered the effects of maintenance on exhaust pollutants, vehicle population and growth, model-year age distribution, average miles driven per age group, anticipated inspection failure rates, and the degradation effects of vehicle usage on emissions. Due to economic and other considerations, Northrop Corporation did not perform any emission testing during this study. Because of extensive testing conducted by other investigators (discussed in Volume I[1]), it was determined that sufficient data existed to calculate the effectiveness measures. Two emission testing projects were completed during the course of this study, one by the Colorado APCD and the other by the EPA, Region 8. Results of these two studies were incorporated with the other investigations to arrive at the following conclusions:

- Both Idle testing and Key Mode testing followed by emission-oriented maintenance of failed vehicles will result in reductions of HC and CO as shown below.

Calendar Year	HC (% Reduction)*		CO (% Reduction)*	
	Idle	Key Mode	Idle	Key Mode
1973	5.2	9.1	6.7	7.2
1976	4.7	8.4	7.0	7.0
1979	4.2	7.6	6.8	6.7
1982	3.5	6.7	6.0	5.7

* Based on 30 percent inspection failure rate and 50 percent emission degradation of serviced vehicles. Vehicle population, distribution, annual mileage, and annual growth varied to reflect historical Federal and State data.

- Emission testing at 30 percent inspection failure rate is nearly as effective as at 50 percent failure rate in terms of emission reductions of HC and CO.

- Key Mode emission tesing at 30 percent inspection failure rate is nearly as effective as 50 percent failure rate in terms of CO but significantly less effective for HC reductions.

- At a 30 percent inspection failure rate, Idle and Key Mode are relatively equal in effectiveness of CO reductions but Key Mode is better for HC reductions.

Reproduced from best available copy.

- Reductions in HC and CO will tend to result in slight increase of emitted NO_x for vehicles without NO_x controls using either test procedure.

- The installation of retrofit devices and systems on uncontrolled vehicles (pre-1968) will result in the following estimated percentage reductions (based on low-altitude testing) for those vehicles only.

	HC	CO	NO_x
Ignition Timing Modification with lean idle adjustment (Alt. #1)	-19%	-46%	-37%
Exhaust gas recirculation with vacuum advance disconnect (Alt. #2)	-12	-31	-48

- For a statewide implementation of retrofit device installation on pre-1968 vehicles only, the annual reductions for the total state is estimated below:

Calendar Year	HC (% Reduction)** Alt. 1	2	CO (% Reduction)** Alt. 1	2
1973	3.9	2.5	9.4	6.3
1976	2.4	1.5	5.6	3.8
1979	1.5	0.9	3.5	2.4
1982	0.9	0.5	2.2	1.5

** Estimates assume that the retrofitted vehicles emission levels deteriorate with age and mileage thereby requiring maintenance. A degradation factor of 50 percent is assumed. Vehicle population growth and attrition factors are included.

- Implementation of an emission inspection and control program would achieve proportionately similar effectiveness in each AQCR. Figures S-1 and S-2 show the program effectiveness in achieving reductions of HC and CO, respectively, in AQCR #2, Metro-Denver.

COST ANALYSIS

A detailed cost analysis model was developed to provide a framework for evaluating the total program costs associated with each of the alternatives. This life-cycle cost model categorized the contributing cost elements into the major submodels of research and development, initial acquisition and investment, and annual operations and maintenance. Results of exercising the model indicate that:

- Research and development costs to implement either Idle or Key Mode are negligible.

Reproduced from best available copy.

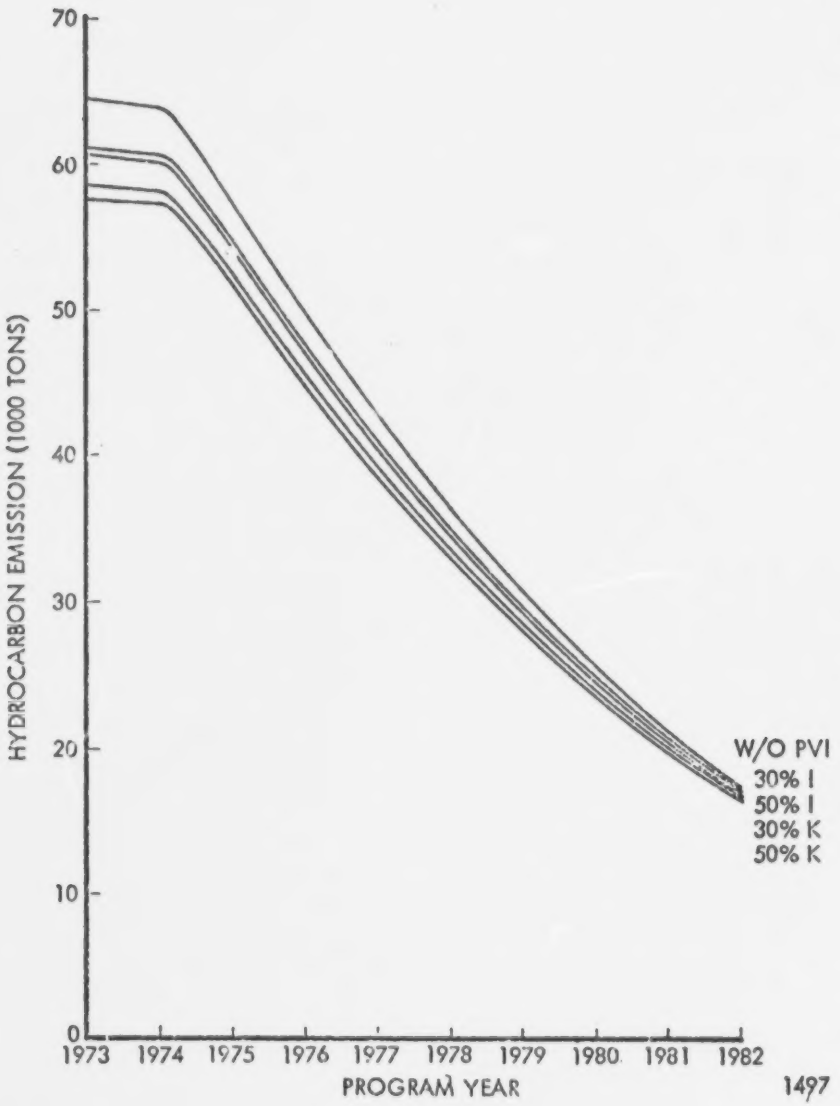


Figure S-1. PVI EFFECTIVENESS (HC) - METRO DENVER

Reproduced from best available copy.

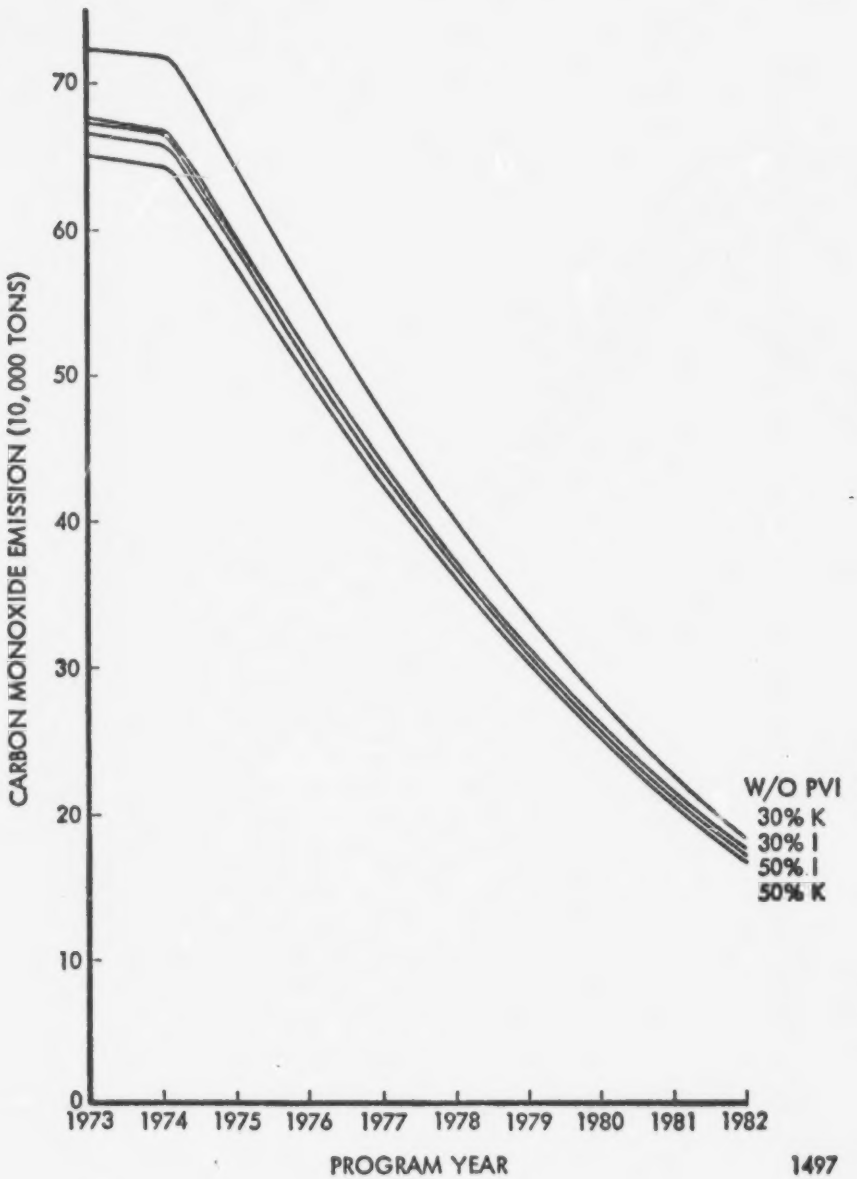


Figure S-2. PVI EFFECTIVENESS (CO) - METRO DENVER

- Initial investment and acquisition costs include site acquisition, building construction or modification, inspector training, equipment purchase and installation, and facility certification. The investment costs for emission inspection are estimated to be as follows:

Alternative	State Costs	Private Industry	Total
Idle - State Operated	$2,172,000	None	$ 2,172,000
Privately Operated	298,000	$ 7,513,000	7,811,000
Key Mode - State Operated	3,333,000	None	3,333,000
Privately Operated	351,000	15,876,000	16,227,000

- Annual operating and maintenance costs for a vehicle emission inspection program include personnel wages and benefits, equipment and building maintenance, inspection facility periodic certification, and program administration and management. The estimated annual cost for each alternative is shown.

Alternative	State Costs	Private Industry	Total
Idle - State Operated	$2,226,000	None	$ 2,226,000
Privately Operated	739,000	$6,190,000	6,929,000
Key Mode - State Operated	2,770,000	None	2,770,000
Privately Operated	909,000	9,536,000	10,445,000

- Emission inspection fee per affected vehicle for each program alternative is based on each program being self-sustaining and assumes an annual inspection

	Idle Test	Key Mode Test
State Operated	$2.10	$2.67
Privately Operated	$5.45	$8.91

- Retrofit devices previously discussed for pre-1968 vehicles would cost between $40-90 installed.

The following comparisons of service and repair costs, business volume, and fuel savings are relatively independent of who operates the inspection facility.

- Vehicle owner typical emission-oriented service and repair average costs for failed vehicles would be as follows:

	Exhaust Controlled Vehicles* 1968 to 1972	Uncontrolled Vehicles* 1967 and Older
Idle Test	$17-36	$25-34
Key Mode Test	13-30	17-36

*This study did not involve extensive vehicle emission testing and servicing to determine cost differences between Idle and Key Mode. The range of costs reflects the results of studies conducted by EPA, ATL, OLI, and Northrop.

A survey of Colorado Automobile Dearlers on the estimated costs for various emission-oriented maintenance activities revealed some differences in expected costs to the vehicle owner. However, no single AQCR was clearly lower (or higher) in all five categories ranging from minor idle adjustments ($6) to major carburetion work ($40).

- The automotive replacement parts after-market and service industry annual business volume is expected to reflect increased vehicle maintenance by the following amount:

	Controlled Vehicles	Uncontrolled Vehicles	1973 Total**
Idle Test	$6,000,000	$ 4,850,000	$10,850,000
Key Mode Test	4,900,000	4,530,000	9,430,000

** Based on 1.3 million vehicles of which 43 percent would be uncontrolled (pre-1968) as of 1973 registrations. Total reflects a 30 percent inspection failure rate during first year.

- Vehicle owner fuel economy is affected by emission-oriented maintenance. Two methods were used to estimate the cost impact. Method #1 as used in the Northrop/California ARB study was based on an empirical relationship between measured changes in vehicle emissions (HC and CO) and fuel consumption. Method #2 as used in the EPA/ATL Study was based on measured carbon content of bagged vehicle exhaus , before and after service. The following estimates are based on 10,000 miles driven annually.

Inspection and Maintenance Concept	Estimated Annual Fuel Savings Method #1	Method #2
Idle	$13-16	Not Calculated
Key Mode	$16-22	Insignificant**

** The ATL/EPA study of 75 1968-1972 vehicles showed the average change for the entire fleet to be insignificant (about $1.45 per vehicle annual fuel savings). Analysis of the test data revealed that if the entire fleet were divided into two groups, increase and decrease in fuel econo y, different results are achieved. The ATL data indicate that 45 percent of the vehicles experienced an increase in fuel economy with an average savings of $17 annually, based on 10,000 miles. On the other hand, 55 percent experienced a loss in fuel economy estimated to be $13 annually.

- Majority of the owners of serviced vehicles will note either an improvement in performance or no detectable change, according to results of Denver testing and servicing performed by the Colorado APCD. This is in agreement with results of emission testing and servicing at low-altitude cities where it was noted that 65 percent of those receiving Idle test and maintenance noted improved performance, and 71 percent of those receiving Key Mode test and maintenance noted improved performance.

PUBLIC OPINION SURVEY

To determine the sentiments of both the urban and rural residents of Colorado regarding the institution of a periodic vehicle emission inspection and control program, 717 owners of private passenger automobiles registered in The State of Colorado were interviewed. There were 267 rural residents and 450 urban residents in the selected sample to establish whether there were any differences in attitudes as a function of residency.

Opinion Research of California designed a questionnaire in conjunction with members of the Northrop Croporation and OLI. The preliminary questionnaire was reviewed and critiqued by the APC Commission, the APC Division staff, and members of the Colorado Advisory Committee on Motor Vehicles Emissions. Opinion Research selected the interviewees based on a modified probability sample design to provide a 95 percent degree of certainty, conducted the interviews by telephone and in person, and tabulated, analyzed, and interpreted the results. The general findings of this survey were that:

- The majority (72 percent) believe that automobiles are the greatest contributors to air pollution, a problem which 61 percent of the respondents consider to be very serious.

- The people feel that the federal and state governments are expending efforts to control air pollution.

- The residents have a definite lack of knowledge relative to the existence of emission controls on their vehicles, the approximate cost to have vehicles inspected and serviced for lower emissions, and the existing requirement that emission control systems are inspected as part of the current vehicle safety inspection program.

- The majority of the people (80 percent total) who would support a vehicle emission inspection program believe it will reduce air pollution, detect defective cars, and eliminate older cars from the highways.

- People who oppose such a program do so because they believe the cost would be too high, it would place a burden on the low income people, and it would be too difficult to enforce.

- Majority of the residents (65 percent) think that all vehicles, regardless of age, should have emission controls, and 83 percent believe that any control program instituted should apply equally to urban and rural residents.

- If an emission inspection program is instituted, 60 percent of the residents would prefer twice-a-year inspection, 27 percent would prefer annual inspection.

  The residents were divided on who should perform the inspection, with 49 percent in favor of private garages and 43 percent in favor of state facilities.

Urban residents would prefer that driving distances to the inspection facilities be less than 5 miles, rural residents prefer the distance be kept to less than 10 miles.

The residents were undecided on a reasonable inspection fee with the largest response (34 percent) favoring $1.50-$2.00.

Residents considered the following alternatives to be reasonable penalties for non-compliance of inspection requirements: monetary fines, warning coupled with fines, penalties in the form of license and/or car removal.

For people that connot afford to pay for required emission control and/or maintenance, the majority feel that one of the following should be considered: Keep vehicle off highway until requirements are satisfied, federal or state governmental assistance should be provided in some form.

- Relative to the existing vehicle safety inspection program, the overwhelming majority (93 percent) are in favor of the concept. Eighty four (84) percent favor the twice-a-year inspection over any other option. The residents are fairly equally divided as to whether they would pay an additional $2 - $4 per year to improve the program. Rural residents tend to drive greater distances to the inspection stations than the urban residents. The large majority (71 percent) definitely favor the private garages doing the safety inspection rather than the state.

COST EFFECTIVENESS ANALYSIS

A cost effectiveness index was developed that combined the results of the effectiveness and cost analyses to facilitate the total program evaluation and comparison of the program alternatives. Based on the yearly effectiveness estimates and the corresponding costs incurred, a ratio of tons emission reduction per dollar spent was calculated for the program duration of 10 years, beginning 1973. The results of this analyses were that:

- For privately operated inspection stations, Idle emission testing is more cost effective than Key Mode testing.
- For state-operated inspection stations, Idle emission testing is slightly more cost effective than Key Mode testing.
- The most cost effective emission inspection program would be Idle testing at State operated inspection facilities.
- Retrofit system installation on pre-1968 model vehicles would be cost effective for a short-term (next 5 years) and immediate solution when coupled with privately owned inspection facilities. However, many problems remain to be resolved such as device accreditation, durability, proven maintenance procedures, acceptable inspection techniques, cost and availability of mass produced units.

SOCIO-ECONOMIC EFFECTS

To ascertain the socio-economic impacts of a vehicle emission inspection and control program, two major efforts were involved. The first was the survey of urban and rural residents, the other was general meetings and discussions with the members of the Advisory Committee. Subject matters for these meetings were primed with Northrop-generated questions relative to financing of inspection and vehicle maintenance and also those affecting consumer protection. Listed below are the social and economic effects of instituting an emission control program. They do not necessarily reflect the majority opinion of the Committee.

- Each registered light-duty vehicle would be subject to the emission inspection and control program.
- The vehicle owner may expect to drive 5 to 10 miles to an inspection station and wait 15-30 minutes while his vehicle is inspected.
- For those vehicles that require emission-oriented servicing, the owner may expect to spend $13-36, on the average, to satisfy established limits. The estimated service-repair time would be 30 minutes, typically.
- To assure uniformity and repeatability of inspection procedures and test results, all vehicle emission inspectors should be qualified and trained, with certification by a State agency; all automotive technicians that perform emission-oriented service and repair should be qualified and trained, with certification by a State agency; all emissions inspection facilities should be state certified initially and periodically; and copies of inspection results and service-repair records should be provided to the vehicle owner.
- To protect the vehicle owner from undue hardship or unfair practices as a result of the emission inspection and control program, vehicle owners should be advised of their rights to appeal an inspection requirement and informed of the related procedures, and they should be advised of the procedures available for filing complaints on unfair practices relative to inspection or maintenance with the appropriate State agency.

LIMITATIONS AND UNCERTAINTIES OF THE STUDY RESULTS

The study attempted to quantify all analytical results whenever possible to facilitate the evaluation and comparison of the program alternatives. As such, any conclusions and recommendations resulting from this investigation must consider the limitations and uncertainties related to the data and information used. These factors are listed below.

- Baseline emission inventories were based on several independent studies involving different test sites, instrumentation, personnel, procedures, and objectives. The emission-altitude relationships derived from the linear regression equations represent the collective test data, within a 95 percent confidence interval (± 5 percent error). However, this may not be representative of the true emissions since the confidence of the total test data is unknown. The EPA data used is expected to be within the 95 percent confidence band, the Colorado and Arizona test data should be within a 90 percent band, or better. Consequently, the baseline emissions for the total State may be within the true value with an error band of about + 10 percent.

  Emission reductions were calculated based on test results from Denver, Los Angeles, and Detroit. The same limitation on the calculated reductions of HC and CO would apply as in the calculation of baseline emissions, with a confidence level of about 90 percent.

  The Arizona vehicle emission test data did not provide sufficient information on NO_x to develop a data base from which further analysis could be performed. Due to numerous irregularities, inconsistencies, and errors in the recorded test data, the computer-processed information on several thousand vehicles did not provide adequate data to determine emission levels of NO_x at the various altitudes in Arizona. While the Arizona emissions van was deployed in Colorado, the NO_x measurement capability was lost due to equipment malfunction. Therefore, no NO_x information is available from these Colorado tests. The EPA programs referenced elsewhere in this report included NO_x measurements of 1968-1971 vehicles at Denver. These studies provided data only on controlled (post 1963) vehicles. Considering these shortcomings, no attempt was made to estimate and project NO_x baseline emissions or the effects of maintenance service and repair.

- The cost estimates for the program alternatives were based on data from equipment manufacturers, previous studies, and from the Colorado APCD staff. As such they represent the best available data. However, it must be recognized that some cost estimates were based on unit costs (such as value per square foot, value per 100 units) which may be oversimplifying and under-estimating the true cost of small lot purchasing. In addition, escalation factors and depreciation costs of building and instrumentation may not be representative of actual implementation. With these limitations considered, the confidence placed on the initial investment costs and the annual operating costs would be about 85 percent.

- Qualitative factors such as future technology in emission control, private sector willingness to invest and participate in statewide programs, and effects of 1975 federal emission warranty requirements were evaluated on a subjective basis.

Recommendations

The study results and conclusions summarized in the preceding paragraphs are the basis for the recommendations discussed below. These recommendations have been categorized relative to emission inspection, retrofit systems, and future activites. A task schedule is shown in figure S-3.

Emission Inspection

It is recommended that beginning in 1973 the private sector facilities performing the current safety inspection be upgraded to perform Idle emission testing. The following tasks should be completed during the initial months of the program.

The Air Pollution Control Division (APCD), in conjunction with the Motor Vehicle Division (MVD), should accomplish the following:

Announce to the private sector facilities the requirements for performing Idle emission inspection (see paragraph 3.2, volume II).

Select candidate facilities for a pilot program involving at least three AQCR, Metro Denver being one of these. The other two should be selected with respect to the mean altitude of principal cities, one lower and the other higher than Metro Denver (see paragraph 2.7, volume II).

Establish the training curriculum, identify training facilities, schedule the necessary classes, notify the affected automotive centers, and certify the inspectors (see paragraph 3.2, volume II).

Develop and implement a plan to review and distribute the test procedures, insure that selected facilities have the necessary instrumentation and trained inspectors, and provide a program timetable.

Develop a plan to select test vehicles for the pilot program. It is recommended that fleet vehicles from governmental agencies, large businesses, and rental agencies be used, along with voluntary light-duty vehicles.

Establish the inspection failure limits for HC and CO. For a 30 percent failure rate, it is recommended that the following limits be considered during the pilot program.

MODEL YEAR	HC	CO
1968 and newer	500 ppm	6%
1967-1963	1000 ppm	10%
1962 and older	1000 ppm	10%

Compile and evaluate inspection data and servicing information to evaluate pilot program effectiveness, to confirm or revise failure limits, and to generate data for the Public Relations Office.

The APCD, in conjunction with the MVD and the Air Pollution Control Commission, should analyze the effectiveness of the pilot program, identify areas requiring modification, and assess the effects and impact of the modified program. Based on this analysis, the joint committee may then institute the necessary changes and develop a plan for statewide implementation.

The Public Relations Office, Department of Health, in conjunction with its counterpart in the Department of Revenue, should develop a public indoctrination program to inform the residents of the implementation plan, the benefits of emission inspection and maintenance, the approximate costs to the vehicle owners, and the similarities and differences between vehicle safety and emission inspection, (see section 6, volume II).

The APCD, in conjunction with the Office of Consumer Affairs within the Department of Law, the MVD, and other responsible state agencies, should review existing and proposed consumer protection plans relative to unfair practices in vehicle inspection and vehicle service and repair, with respect to penalties for non-compliance, and relative to procedures for requests for waivers and filing of complaints. Additional plans should be provided for as required. These plans should be summarized and made available to the general public at the initiation of the statewide program (see paragraphs 6.6 and 7.4, volume II).

Retrofit System Installation

It is recommended that study projects be conducted to fully evaluate the effectiveness and associated costs of installing feasible retrofit systems for emission control and reduction. This study has defined the effectiveness of two types known to be technically and economically feasible at low-altitude cities. These are (1) ignition timing modifications coupled with lean air-fuel mixture adjustment and (2) exhaust gas recirculation with vacuum advance disconnect. These systems were tested on pre-1968 vehicles only during an EPA study. The effects of altitude on the system performance and exhaust emissions have not been investigated. Additionally, periodic maintenance requirements need to be better defined if these systems are to become mandatory.

The high altitude modification packages designed by Pontaic Motor Division in Denver appear to effect lower emissions on 1972 General Motors vehicles. It is recommended that a study project be conducted to fully evaluate this concept.

The following tasks should be completed during the early months of the pilot program for vehicle inspection. Study projects should be designed for completion within a year after the Idle emissions inspection pilot program is initiated such that recommended systems may be installed beginning in 1974. Figure S-3 shows the task schedule. It is recommended that the APCD accomplish the following:

a. Design a study project to evaluate the effectiveness of (1) ignition timing modification coupled with lean air-fuel mixture adjustment and (2) exhaust gas recirculation with vacuum advance disconnect on pre-1968 vehicles relative to their effects on performance and emission reduction at various operating altitudes. Results of this project should be correlated with the EPA study (reference 5, volume II) on these same devices.

b. Design a study project to evaluate the effectiveness of the retrofit devices described above on 1968-1972 vehicles.

c. Design a study project to evaluate the technical and economic feasibility of the GM high-altitude modification packages. The experiment design should consider factors such as applicability to all light-duty 1968-1972 vehicles, applicability to 1963-1967 vehicles, mass productibility and manufacturing/licensing constraints, emission reductions, effects on vehicle performance, effects on fuel economy, maintenance requirements, installation requirements, and acquisition and installation costs.

d. Conduct these study projects, or cause them to be conducted by independent contractor(s), within calendar year 1973.

Contingent on the study projects results, it is recommended that private garages install the selected retrofit systems following the manufacturer's or the study project procedures. The systems should then be periodically inspected, if required, as part of the Idle emissions-vehicle safety inspection program. Based on the analysis of study project results, the Colorado APCD in conjunction with the MVD should establish the installation schedule, inspection procedures, failure criteria, and recommended servicing.

Future Activities and Studies

It is recommended that the Colorado Air Pollution Control Commission and the Department of Health investigate the possibility of the Federal EPA recalling all 1972 model-year vehicles which fail to comply with the Federal emission standards. A contracted study for the EPA is currently in progress in five cities of the U. S. to establish whether the 1972 vehicles are meeting the standards.

The EPA surveillance programs on 1970 and 1971 vehicles (references 24 and 25) indicated that emissions from Denver vehicles were significantly higher than those in Los Angeles, Houston, and Detroit. The recently completed EPA-ATL study in Denver included ten 1972 model-year vehicles. Two of the vehicles had HC emissions less than the 1972 CVS standards, none had CO levels less than the standards. These 1972 vehicles mean HC value was 4.72 grams per mile and the CO value was 74.9 grams per mile compared with the Federal 1972 CVS standards of 3.4 and 39 grams per mile, respectively.

APCD Capabilities

It is recommended that the Colorado Air Pollution Control Division develop or strengthen its capabilities:

a. To evaluate existing and future vehicular emission control concepts and systems, to assess manufacturer's claims for add-on after-market devices and techniques in reducing vehicle emissions, and to qualify and certify proven emission-reducing systems and techniques for public use.

b. To review emission test procedures, test results, and surveillance data to ascertain program effectiveness, revise inspection failure limits, and modify air quality improvement strategies.

c. To evaluate vehicle emission measurement instrumentation requirements, current and future.

d. To keep abreast of the latest developments in vehicle emissions control strategies and on Federal requirements and standards for newer vehicles.

e. To conduct on-going investigations on research and development projects related to vehicle emission reductions.

Emission Inspection Limits

The 1973 vehicles are required to meet Federal NO_x standards of 3.0 grams per mile based on the 1972 CVS Federal Test Procedures. Due to lack of sufficient data, no recommendations are made herein relative to establishing any NO_x inspection limits. Instrumentation for NO_x measurements was listed as an optional equipment for stations conducting Idle test. Limits for HC and CO were based on the emissions-altitude relationships developed in this study. It is recommended that the APCD compile and analyze the pilot program inspection data to verify these relationships, modify as necessary, and arrive at a better definition of inspection failure criteria for statewide implementation.

The APCD should also initiate plans to monitor NO_x levels of 1973 model year vehicles. This could be accomplished by licensed new car dealers who elect to participate in the pilot program. Analysis of the NO_x data would result in the establishment of NO_x limits for 1973 and newer vehicles equipped with NO_x controls.

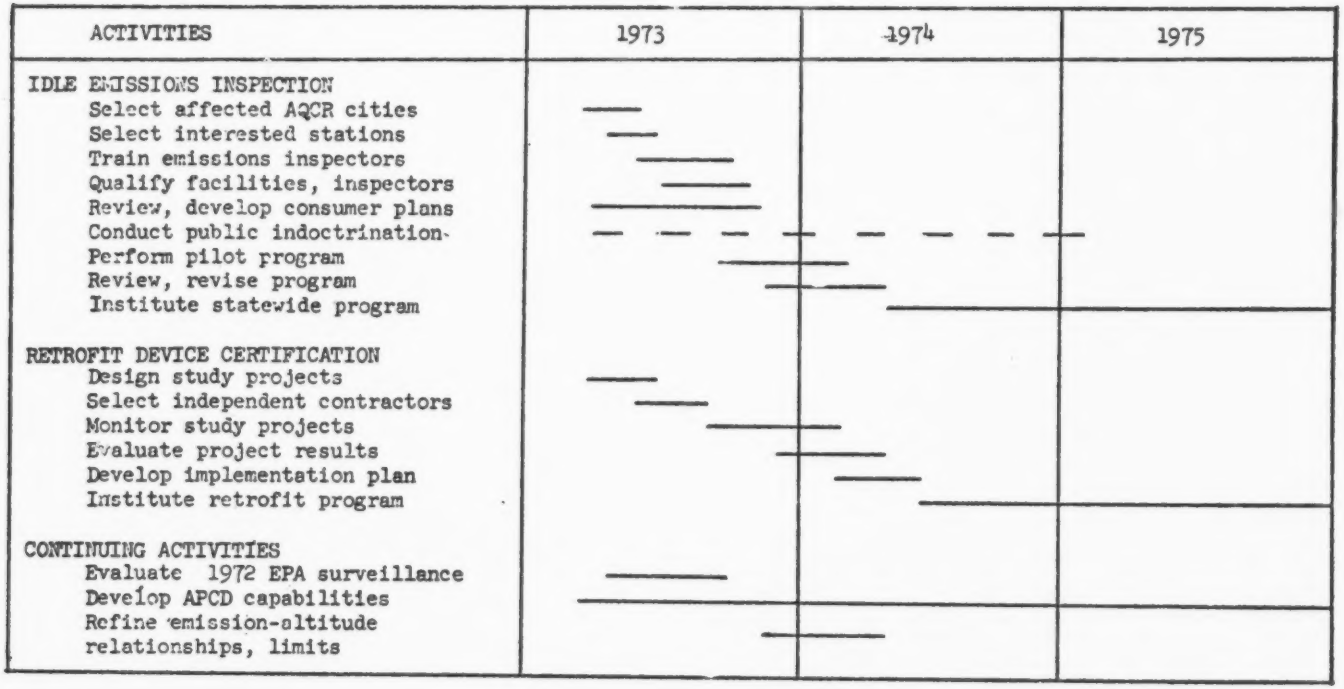


Figure S-3. RECOMMENDED PROGRAM SCHEDULE

APPENDIX G
TITLE 40 - APPENDIX N

Appendix N - Emissions Reductions Achievable Through Inspection, Maintenance and Retrofit of Light Duty Vehicles

1. General

This Appendix presents estimates of emissions reductions that, in the judgment of the Administrator, are likely to be achievable through application of inspection, maintenance, and retrofit measures to in-use motor vehicles. To the extent possible, these estimates are based on empirical data. However, lack of data in some areas has necessitated some extrapolation of empirical data using engineering judgment. The sources of empirical data and the bases for judgments are discussed in paragraph 6 of this Appendix.

The emissions reductions estimates presented herein are subject to considerable uncertainty. The emissions reductions actually realized in a transportation control program may be greater or less than the estimated reductions. The estimates should therefore be regarded as useful primarily for current planning purposes. Any transportation control plan incorporating in-use vehicle emission control approaches, whether those specifically cited in this Appendix or alternatives proposed by a State, must provide, as required by 40 CFR Section 51.19d, for field verification of the emissions actually achieved in the implemented programs and, as required by Section 110(a)(2)(H) of the Act, for any revisions of the transportation control plan that may be indicated thereby.

The approaches to in-use vehicle emissions control cited herein are those judged to be most generally applicable by the Administrator considering the information currently available to him. States are encouraged to consider other approaches that may be applicable to their particular situations. Data and analyses supporting the emissions reductions claimed for alternative approaches must be submitted with the Transportation Control Plan. Several alternative approaches are discussed in the Environmental Protection Agency report entitled "Control Strategies for In-Use Vehicles," available from EPA, Mobile Sources Pollution Control Program, 401 M. Street, S.W., Washington, D.C. 20460.

The States are also encouraged to give consideration to transportation control measures based on reductions in vehicle use and traffic flow measures. Nothing in this Appendix is intended to suggest that transportation control approaches based on inspection, maintenance, and retrofit should necessarily be considered preferable to approaches based on reductions in vehicle use or traffic flow measures.

2. Definitions

a. "Precontrolled vehicles" means light duty vehicles sold nationally (except in California) prior to 1968 model year;Light duty vehicles sold in California prior to the 1966 model year.

b. "Controlled vehicles" means light duty vehicles sold nationally (except in California) in the 1968 model year and later;light duty vehicles sold in California in the 1966 model year and later.

c. "Loaded emissions test" means a sampling procedure for exhaust emissions which requires exercising the engine under stress (i.e., "loading") by use of a dynamometer to simulate actual driving conditions. These include the key-mode test, Acceleration, Cruise, Idle and Deceleration (ACID) test, 7 mode test, and others.

d. "Idle emission test" means a sampling procedure for exhaust emissions which requires operation of the engine in the idle mode only.

e. "Retrofit" means the addition or removal of an item of equipment, or a required adjustment, connection, or disconnection of an existing item of equipment, for the purpose of reducing emissions.

f. "Inspection/maintenance" means a program to reduce emissions from in-use vehicles through identifying vehicles that need emissions control related maintenance and requiring that maintenance be performed.

g. "Idle adjustments" means a series of adjustments which include idle RPM, idle air/fuel ratio and basic timing.

3. Inspection/Maintenance of Light Duty Vehicles

a) Reductions

The following average annual reductions in exhaust emissions per vehicle are estimated to be achievable through implementation of an inspection/maintenance program using a loaded emission test:

Hydrocarbons	12%
Carbon Monoxide	10%
Nitrogen Oxides	0%

To obtain these reductions an inspection/maintenance program must provide for inspection of each vehicle at least once per year. More frequent inspection and maintenance is expected to provide larger average emissions reductions, although at greater cost. During the first inspection cycle of an inspection/maintenance program, emissions reductions may be assumed only to the estent consistent with the portion of the vehicle population that has been inspected by that time.

b. The average reductions cited above are applicable for all gasoline-powered light duty motor vehicles (except motorcycles) which are included in the inspection/maintenance program.

c. Requirements

An acceptable inspection/maintenance program must include:

i) Provisions for regular periodic inspection of all vehicles for which emissions reductions are claimed.

ii) Provisions for the establishment of inspection failure criteria consistent with the claimed reductions.

iii) Provisions to insure that failed vehicles receive the maintenance necessary to achieve compliance with the inspection standards. This might include sanctions against individual owners, retest of failed vehicles following maintenance, a certification program to

insure that repair agencies performing the required maintenance have the necessary equipment and knowledge to perform the tasks satisfactorily, and/or other measures.

iv) A program of enforcement to insure that vehicles are not intentionally readjusted or modified subsequent to the inspection and/or maintenance in such a way as would cause them to no longer comply with the inspection standards. This might include spot checks of idle adjustments and/or a suitable type of physical tagging.

d. Alternative Approaches

Inspection/maintenance programs employing approaches other than emissions testing using a loaded emissions test may be capable of achieving emissions reductions for vehicles of certain model years. Idle emissions inspection, extensive engine parameter inspection, and mandatory maintenance procedures are discussed in the Environmental Protection Agency report "Control Strategies for In-Use Vehicles." Inspection/maintenance approaches other than those using a loaded emissions test, or emissions reductions greater than those cited in paragraph 3.a while using a loaded emissions test, will be acceptable only if sufficient data and analyses are provided to justify the emissions reductions claimed.

4. Retrofit of Light Duty Vehicles

a) Reductions

The following reductions in exhaust emissions per vehicle

are estimated to be achievable through installation of specific classes of retrofit devices on the specific model year classes of vehicles noted. Since retrofitted vehicles are expected to be subject to periodic inspection and maintenance (see Paragraph 4.c), the reductions cited are to be applied to a maintained vehicle emissions baseline. For example, if a 12% reduction in hydrocarbon emissions is claimed for inspection/maintenance, the reduction in hydrocarbon emissions due to a retrofit approach should be calculated after the vehicle's original emission rate for hydrocarbons has been reduced by 12%.

i) Pre-controlled vehicles

Retrofit Option	Average Reduction per Vehicle HC	CO	NO_x
Lean idle Air/Fuel Ratio Adjustment and Vacuum Spark Advance Disconnect	25%	9%	23%
Oxidizing Catalytic Converter and Vacuum Spark Advance Disconnect	68%	63%	4?%
Air Bleed to Intake Manifold	21%	58%	0%
Exhaust Gas Recirculation and Vacuum Spark Advance Disconnect	12%	31%	48%

ii) Controlled vehicles

Retrofit Option	Average Reduction per Vehicle HC	CO	NO_x
Oxidizing Catalytic Converter	50%	50%	0%
Exhaust Gas Recirculation	0%	0%	40%

During the installation phase of a retrofit program, emissions reductions may be assumed only to the extent consistent with the portion

of the vehicle population on which retrofit devices have been installed by that time.

b) Applicability

The emissions reductions cited above for pre-controlled vehicles are applicable to all gasoline-powered light duty motor vehicles (except motorcycles) sold nationally (except in California) prior to the 1968 model year or in California prior to the 1966 model year.

The emissions reductions cited above for installation of oxidizing catalytic converters on controlled vehicles are applicable to all gasoline-powered light duty motor vehicles (except motorcycles sold nationally (except in California) in the 1968 through 1974 model years or in California in the 1966 through 1974 model years.

The emissions reductions cited above for installation of exhaust gas recirculation on controlled vehicles are applicable to all gasoline-powered light duty motor vehicles (except motorcycles) sold nationally (except California) in the 1968 through 1972 model years or in California in the 1966 through 1971 model years.

c) Requirements

An acceptable retrofit program must include:

i) A method of insuring that there will be available an adequate supply of retrofit components and that these components will be capable of achieving the claimed reductions. This may require a carefully designed retrofit certification procedure.

ii) Provisions for emissions testing at the time of retrofit installation or some other positive assurance that the retrofit device is installed and operating correctly.

iii) Provisions for inspection and maintenance of each retrofitted vehicle at least once per year.

iv) Provisions for the establishment of inspection standards for retrofitted vehicles consistent with the emissions reductions claimed. Particular attention must be paid in this regard to catalytic converter retrofits as the reductions cited in paragraph 4.a do not include possible irreversible catalyst deterioration over time.

v) Provisions to insure that vehicles failing inspection receive the maintenance necessary to achieve compliance with the inspection standards.

vi) In the case of retrofit programs that include the use of catalytic converters requiring unleaded fuel, provisions to insure that vehicles utilizing this type of retrofit will not use leaded gasoline and that adequate supplies of lead-free gasoline will be available if Federal regulations will not insure availability, and provided that such provisions are not in violation of Section 211(e)(4) of the Act.

d) Alternative Approaches

Retrofit programs employing approaches other than those cited above may be capable of achieving emissions reductions for vehicles of certain model years.

For example, addition of vacuum spark advance disconnect to the air bleed to intake manifold approach may be feasible for pre controlled vehicles. Alternative retrofit approaches or retrofit emissions reductions greater than those cited in paragraph 4.a will be acceptable only if sufficient data and analyses are provided to justify the emissions reductions claimed.

5. Inspection/Maintenance or Retrofit of Vehicles Other than Light Duty Vehicles

The inspection/maintenance and retrofit approaches discussed above may be applicable to certain classes of motor vehicles other than those cited. In particular, the States are encouraged to consider the application of such approaches to motor vehicles in the 6,000 to 10,000 lb. GVW class. In many cases, these vehicles are constructed and operated in a manner similar to light duty vehicles. However, the present lack of empirical test data for application of inspection/maintenance or retrofit approaches to vehicles of this type prevents the inclusion of data on achievable emissions reductions for such vehicles in this Appendix. Transportation control strategies employing inspection/maintenance or retrofit of vehicles other than light duty vehicles will be acceptable only if sufficient data and analyses are provided to justify the emissions reductions claimed.

6. Bases for Emissions Reductions Cited in Paragraphs 3 and 4

a) Inspection/Maintenance

The reductions cited in paragraph 3.a for inspection/maintenance using a loaded emissions test were drived from empirical test data obtained by EPA in evaluating the initial emissions reductions

achieved when a fleet of pre-controlled and controlled light duty vehicles was subjected to an emissions inspection test and the the vehicles failing that test were serviced in private maintenance garages. The results of that study are presented in the EPA report "Control Strategies for In-Use Vehicles." The observed initial reductions were 25 percent (HC), 19 percent (CO), and 0 percent (NOx).

It is expected that in an actual inspection/maintenance program the average emissions reductions achieved will be substantially less than the initial reductions observed in the study, since there will be deterioration of emissions-related components and adjustments between periodic inspection and maintenance events. While the currently available empirical data on such deterioration are inadequate to accurately predict the consequences of this effect, some correction for deterioration is necessary. Therefore, giving consideration to the current frequency of voluntary maintenance and the emissions reductions typically achieved by existing maintenance procedures, it has been assumed that linear deterioration to before-maintenance emissions levels will occur over the twelve month period following maintenance. As a result, the average effectiveness for annual inspection is estimated to be one-half of the initial effectiveness following maintenance.

Empirical data on the effectiveness of inspection/maintenance programs in reducing emissions are available only for light duty vehicles through the 1971 model year. The effectiveness of inspection/maintenance programs in reducing emissions from future model year vehicles will depend primarily on the extent to which emissions from

those vehicles increase in use as a result of repairable malfunctions and on the ability of the inspection test to accurately identify vehicles having such malfunctions. These factors can be empirically evaluated only after substantial numbers of such vehicles have been in use for some time. However, for implementation planning purposes, it has been assumed that emissions reductions estimated to be achievable for current light duty vehicles will be applicable for future model years as well.

Available empirical data indicate that initial emissions reductions attainable through inspection/maintenance programs using an idle mode emissions test, are comparable to those attainable when a loaded emission test is used. However, it is anticipated that, in practice, programs based on an idle mode test only will be substantially less effective than these data suggest. This is because only limited maintenance (in contrast to the extensive maintenance performed in the empirical studies) is generally required to achieve compliance with an idle emissions test. Such maintenance may not achieve improvements in true mass emissions under typical driving conditions. Furthermore, an idle mode test alone can often be satisfied with combinations of engine adjustments that accomplish little or no true emissions reductions in terms of emissions measured over a driving cycle representative of typical urban driving conditions (the Federal Certification Test Procedure). Quantitative estimates of the loss in emissions reduction effectiveness due to these effects are not presently available.

Inspection and maintenance programs using engine parameter inspection or mandatory maintenance approaches may also be effective for vehicles of certain model years. However, such approaches must be tailored to relate to the specific engine and emissions control systems of the vehicles to be inspected and/or maintained. Depending upon inspection and maintenance procedures and the number and choice of engine parameters included in the program, substantial variations in emissions reductions are to be expected.

Because of the above considerations, it has been concluded that generally-applicable estimates of achievable emissions reductions can be derived from currently available empirical data only for programs which use a loaded emissions test. States considering inspection and/or maintenance programs based on alternative approaches should take the factors mentioned above into account where estimating and justifying emissions reductions expected from such programs. More detailed discussion of these matters may be found in the EPA report "Control Strategies for In-Use Vehicles."

b) Retrofit

i) Pre-controlled vehicles

The reductions cited in paragraph 4.a for pre-controlled vehicles are based upon empirical test data obtained in evaluating the initial emissions reductions obtained when various types of retrofit emission controls systems were fitted to fleets of tuned pre-controlled light duty vehicles.

The results of these studies are presented in the EPA "Control Strategies for In-Use Vehicles." In each case, the mean emissions reductions observed have been adopted as being most representative of the initial emissions reductions which may be achieved in an actual retrofit program.

Only very limited empirical data are currently available on the deterioration of emissions performance of retrofit vehicles. These data, which are discussed in the EPA report "Control Strategies for In-Use Vehicles," indicate the need for periodic inspection and maintenance of retrofitted vehicles if the attainment and maintenance of the retrofit emissions reductions cited in paragraph 4.a is to be assured. Based upon the available empirical data and the requirements for inspection and maintenance of retrofitted vehicles at least once per year, and considering the nature of the emissions control techniques employed in each retrofit approach, it appears that the average annual emissions reductions per retrofitted vehicle can approach the observed mean initial reductions if suitable inspection and maintenance criteria are adopted. Accordingly, it has been assumed that observed initial emissions reductions will not be affected by deterioration.

ii) Controlled vehicles

Empirical data which could serve as a basis for estimating emissions reductions achievable through retrofitting controlled light duty vehicles are quite limited. As a result, the emissions reductions cited for this class of vehicles in paragraph 4.a

were developed by extrapolating the empirical data for retrofitting pre-controlled light duty vehicles.

The techniques of lean idle air/fuel ratio adjustment, vacuum spark advance disconnect, and air bleed to intake manifold are not considered to be generally applicable to controlled vehicles. This is because these emissions control approaches are either incorporated into or may be inconsistent with emissions control techniques already applied to many controlled vehicles.

Exhaust gas recirculation (EGR) is considered generally applicable only to those vehicles not substantially controlled for nitrogen oxides emissions. Therefore, EGR as a retrofit approach is applicable in 1968 through 1972 models sold nationwide (outside of California), except for an insignificant number of 1972 vehicles already equipped with EGR. Incorporation of EGR into a significant number of 1972 models sold in California limits the general applicability of this retrofit approach to 1966 through 1971 controlled vehicles sold in California.

Oxidizing catalytic converters are considered to be potentially applicable as retrofits through the 1974 model year. Beyond the 1974 model year, the presently anticipated design of emissions control systems required to meet Federal new car emissions standards is considered to preclude retrofitting using currently available retrofit technology.

The following paragraphs describe the bases for the emissions reductions cited for retrofit of controlled vehicles.

Oxidizing Catalytic Converters

Empirical data indicate that catalytic converter retrofits to pre-controlled vehicles can achieve emissions reductions of 68 percent (hydrocarbons), 63 percent (carbon monoxide), and 48 percent (nitrogen oxides) when combined with vacuum spark advance disconnect. Presently available data suggest that deterioration may not be significant with retrofit-type catalysts.

Experience to date with prototype 1973 emissions control systems suggests that retrofit catalytic converters are capable of achieving substantial reductions of hydrocarbon and carbon monoxide emissions from controlled light duty vehicles. While studies of pre-controlled vehicles have provided evidence that retrofit catalysts may also achieve some reduction of nitrogen oxides emissions, the extent of this reduction is too highly dependent on the air/fuel ratio in the catalyst to be extrapolated to controlled vehicles with reasonable certainty.

In experiments conducted to date, installation of retrofit catalysts on pre-controlled vehicles has been accompanied by vacuum spark advance disconnect. In addition, a lean idle air/fuel ratio adjustment has normally been included in the installation procedures. As neither of the latter two modifications is generally applicable to controlled vehicles, it is prudent to anticipate that reductions of hydrocarbon and carbon monoxide emissions achieved by retrofit catalysts on controlled vehicles may be less than those observed with pre-controlled vehicles.

The cited emissions reductions of 0 percent (hydrocarbons and Carbon monoxide) and 40 percent (nitrogen oxides) are estimates consistent with the foregoing considerations and the results obtained with pre-controlled vehicles.

Exhaust Gas Recirculation (EGR)

Emissions reductions of 12 percent (hydrocarbons), 31 percent (carbon monoxide), and 48 percent (nitrogen oxides) have been observed as a result of retrofitting pre-controlled light duty vehicles with EGR accompanied be vacuum spark advance disconnect. Experience with 1973 emissions control systems for new cars suggests that EGR retrofits can achieve substantial reductions of nitrogen oxides emissions from controlled vehicles not already equipped with EGR or equivalent nitrogen oxides emissions control systems.

Much of the hydrocarbon control and some of the nitrogen oxides control observed with EGR retrofits to pre-controlled vehicles is attributable to the vacuum spark advance disconnect. This is not generally applicable to controlled vehicles. In addition, the design features responsible for much of the carbon monoxide reduction observed with pre-controlled vehicles are likely to be already incorporated into many controlled vehicles. It is therefore prudent to expect that EGR retrofits to controlled vehicles may achieve somewhat smaller reductions of nitrogen oxides emissions than have been observed with pre-controlled vehicles and no reductions of hydrocarbon and carbon monoxide emissions.